Research Report No. 46 Computer-aided Planning of Regional

Computer-aided Planning of Regional Sludge Disposal Systems

Research Report No. 46

KE204-6-C028

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767
.C66
1976

**Research Program for the Abatement of Municipal Pollution
under Provisions of the Canada-Ontario Agreement
on Great Lakes Water Quality**

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COMPUTER-AIDED PLANNING OF REGIONAL SLUDGE DISPOSAL SYSTEMS USER'S MANUAL

by

B & P Silveston, Engineers
Kitchener, Ontario
and
Canadian Federation of Mayors and Municipalities

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
PROVISIONS OF THE CANADA-ONTARIO
AGREEMENT ON GREAT LAKES WATER QUALITY

Project No. 73-5-8

September, 1976

This document may be obtained from -

Training and Technology Transfer
Division (Water)
Environmental Protection Service
Environment Canada
Ottawa, Ontario K1A 0H3

Ontario Ministry of the Environment
Pollution Control Branch
135 St. Clair Avenue West
Toronto, Ontario
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Minister of Supply and Services Canada 1976
Cat. No. En43-11/46

ISBN 0-662-00217-2

ISSN 0381-2146

ABSTRACT

This manual is intended to serve a number of purposes. First of all, it is a training manual which introduces potential users to the concepts of computer-aided planning, the models for sludge disposal that are imbedded in the computer programs, and the information which must be developed in order to use the programs. The manual is also a source book for setting up a data collection program to be used with computer-aided planning. It contains the coding which transforms the data into the proper form for processing by a computer. Thirdly, the manual provides detailed information on the structure of the computer program, so that it can be modified for special purposes or expanded to handle different planning problems such as refuse disposal. Only a minor attempt has been made to indicate the chronology of the project, the sources of information used and the problems tackled during its active life. In a very real sense, the User's Manual is the final product of work undertaken in the project.

A general purpose computer program applicable to the optimization of regional sludge disposal systems is described. The model upon which the computer program is built is a network of transport routes connecting nodes which represent sources of sewage sludge, intermediate facilities for processing or the temporary storage of sludge (such as vacuum filters or lagoons), and dead-end facilities for ultimate disposal (such as landfill or land spreading sites). Since the spreading of sludge on land is an alternative which will usually be considered, and as this is permitted only within certain portions of the year, the model permits intermediate facilities to be designated for winter storage of sludge which would otherwise be distributed to dead-end facilities which are seasonally restricted.

The engineer-planner within the computer-aided method retains his essential position, but the nature of the work he does is changed by the technique. In addition to data collection, it is his responsibility to postulate sets of facilities (without specifying their size, but only the upper limits on size) which are to be considered within the computer program. Using given transport costs per unit volume of sludge (as functions

of travel time) and given functions of facility cost versus size, which must also be supplied by the engineer-planner, the computer program finds what combinations of facilities meet the disposal requirements at least cost and how sludge should be distributed from the sources to these facilities. The computer program actually prints out lists of the near optimal solutions to the planning problem. It then becomes the responsibility of the engineer-planner to analyse these solutions and develop, through the use of case studies, a solution which gives low cost sludge disposal and also satisfies aesthetic social and political considerations as well.

To test the performance of the computer program, the Regional Municipality of Niagara supplied cost data, lists of potential disposal facilities and their locations, and data on sludge productions at the various waste treatment plants located within their boundaries. A detailed study of sludge disposal in the Regional Municipality was not undertaken; however, runs were made to examine the sensitivity of the computer generated solutions to assumptions in the cost data. Runs were made also for projected sludge production in 1980 and 1990. This yielded a picture of the development of the sludge disposal system with time. It is perhaps this aspect which may be most valuable to the engineer-planner, since long term studies are hardly conceivable without computer assistance.

A second computer program was developed in the course of this project to plan an optimal transport system to move from sludge to sources to the chosen disposal facilities. Given depot locations for the trucking fleet, the carrying capacity of trucks, and an operating factor, the computer program generates the least cost schedule of pickups for the sludge disposal network. Allowing depot locations and truck sizes to vary, a case study approach can be used to find an optimal transport system for sludge. Conditions of this contract only permitted development of the basic computer program for this task. Although this program has been tested on a hypothetical example, application to a real system will probably be necessary before it can be released for general use. Some polishing of the program to simplify data input and improve the computer printout is also required.

RÉSUMÉ

Le présent ouvrage se propose de répondre à plusieurs besoins. Nous avons voulu créer une introduction à la planification informatisée, aux modèles d'élimination des boues (qui se trouvent intercalés dans les programmes d'ordinateurs) ainsi qu'aux données de base servant à actualiser les programmes. Nous avons voulu en faire une méthode fondamentale pour recueillir les données qu'exige la planification automatisée. Le manuel renferme aussi les codes permettant d'adapter les données au traitement informatique. Enfin, il expose en détail la structure du programme de planification afin que les utilisateurs puissent l'adapter à des fins précises ou le développer pour résoudre certains problèmes particuliers au traitement des déchets. Nous n'avons accordé qu'une importance secondaire à l'ordre chronologique des travaux, aux sources de renseignements et aux problèmes qui se sont posés. Ce manuel est, en fait, le résultat ultime du projet réalisé.

Le lecteur y trouvera la description du programme informatique général conçu pour optimiser les procédés régionaux de traitement des boues. Ce programme s'inspire du modèle d'un réseau de transport reliant les sources de boues résiduaires à certaines stations intermédiaires de transformation ou d'entreposage temporaire (filtres aspirants ou bassins de stabilisation) et, enfin, aux aménagements terminaux où elles se dispersent (lieux d'enfouissement ou d'épandage). Puisque l'épandage est courant, mais ne peut se faire que hors de la saison du gel, le modèle prévoit que certaines stations intermédiaires désignées devraient retenir, pendant l'hiver, les boues qui en temps normal sont acheminées vers les dégagements terminaux.

L'ingénieur planificateur, secondé par l'informatique, demeure indispensable, mais la nature de son travail se trouve modifiée. En plus de recueillir les données, il a la tâche de définir les ensembles d'installations (il suffit d'en estimer le débit maximal) qui interviendront dans le programme d'ordinateur. A partir du coût unitaire du transport des boues (en fonction du temps) et des fonctions coût-capacité des installations, tous fournis par l'ingénieur planificateur, le programme détermine les combinaisons d'installations les plus économiques et aussi

les modes de distribution qui conviennent le mieux depuis les sources de boues jusqu'aux stations identifiées. En fait, l'ordinateur produit une liste des meilleures solutions au problème de planification soumis. Il incombe ensuite à l'ingénieur planificateur d'analyser les solutions à la lumière d'un certain nombre d'études de cas. Il en arrive ainsi à proposer un système économique qui satisfait en même temps les considérations d'ordre esthétique, social et politique.

Afin de mettre à l'épreuve l'application du programme informatique, la municipalité régionale de Niagara a fourni des données relatives aux coûts, une liste d'installations possibles précisant leur emplacement, ainsi que des données sur le débit des diverses usines de traitement de la région. En fait, la municipalité régionale n'a pas étudié en détail son système d'évacuation de boues. Cependant, elle a fait des essais du programme, à l'aide d'estimations hypothétiques des coûts, pour en vérifier la sensibilité, à la lecture des solutions fournies par l'ordinateur. La machine en a également obtenu des projections du volume des boues pour la décennie 1980-1990. Comme résultat, nous avons pu établir de profile temporel de l'évolution du système de traitement des boues. C'est probablement cet aspect de la planification informatisée qui intéresse le plus l'ingénieur planificateur. Il lui est très difficile, en effet, de réaliser des études à long terme sans le secours de l'ordinateur.

Un second programme informatique élaboré au cours des nos travaux permet de planifier un systéme optimal pour transporter les boues de la source aux installations identifiées. L'emplacement des dépôts de camions étant connu, ainsi que la contenance des bennes de ces derniers et un certain facteur lié à leur utilisation, le programme livre le schéma de collecte le plus économique. La capacité des camions étant variable ainsi que l'emplacement des dépôts, une étude de cas permet de déterminer le système de transport optimal.

Notre mandat nous a seulement permis d'établir le programme informatique de base. Nous avons pu en faire l'essai au moyen d'une exemple hypothétique, mais il faudra le roder dans des situations réelles avant d'en généraliser l'usage. Il faudra aussi le polir afin de simplifier l'entrée des données et d'améliorer la presentation des résultats à la sortie.

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PREFACE

During the 1950's and 60's, with the impetus of the Ontario Water Resources Commission, numerous sewage treatment plants were built throughout Canada. The result of this, as time went by, was that the problem of sludge disposal became one of concern for many municipalities.

Traditionally, in Canada, the disposal of solid wastes and sewage sludge is the responsibility of each municipality, industry or individual. However, the growth of urban areas, often by amalgamation of many areas, left a number of small plants and dump sites to be operated by one political body.

This, of course, resulted in a two-fold problem: the first, of coordinating the various facilities and, the second, the matter of planning the possible interconnection, enlargements or deletions in the expansion of a growing area.

In addition to the above, public concern about pollution hazards has mounted, with the result that casual dumping is no longer acceptable. This has forced many municipalities to re-examine disposal practices.

Political considerations and spiraling costs have dictated a need for detailed and comprehensive planning in the disposal of waste products. The ready availability of computers now makes this planning possible. The purpose of this report is to show how a proper program with the aid of computers can be of great help in making the proper planning decisions.

The method described in this manual is properly termed "a computer-aided planning method". By no means is it a method whereby one presses a button and out spews reams of paper detailing a regional plan for sewage sludge disposal. The concept is an interactive one. The engineer-planner assembles information on the disposal problem which the computer manipulates to serve up one or more answers. In turn, these cause new questions to be asked, the computer yields new answers, and so on. From this process of question and answer eventually emerges a comprehensive plan for sludge disposal.

Just as in a traditional planning problem, the engineer must project sludge production, select disposal alternatives, examine financing, choose sites and interact throughout with the public at large. The availability of the computer changes none of this. Its role is to sort out the multiplicity in types of facilities, sites and sludge sources into a plan capable of meeting the disposal needs at least cost. The work of the planner remains heavy; the computer provides him with a tool for producing a better plan.

One of the many objectives of the Canadian Federation of Mayors and Municipalities is the sharing of information among member municipalities to permit each to provide better services to its citizens at lower cost. The Federation's contribution to this manual recognizes its legitimate responsibility to provide useful information to its members. The planning method which this manual presents is felt to one whose use is well within the capabilities of consultants who provide planning for smaller municipalities and the planning departments of the larger municipal units. Although the computer program which forms such an important part of the method is efficient and skillfully written, it does not represent the ultimate in sophistication. A compromise has been made between the storage requirement of the computer program, its running cost, versatility and ease of use on one side, and the completeness of the plan it furnishes on the other. Interaction between computer and engineer required by this compromise is believed to be a benefit rather than a burden.

1. INTRODUCTION

Two topics to be dealt with in this chapter are the purposes of this manual and how it is best used.

For those interested in the history of how and why this manual developed, a special appendix (Appendix I) entitled "Project History" has been added.

1.1 Objectives

This manual is intended to serve as a source book; it is both an introductory text and a detailed reference. For administrators, its purpose is to show the complexities of planning for sludge disposal, to introduce computer-aided planning and the type of information required to use it, and lastly to indicate computing requirements. After reviewing this manual an administrator should be able to estimate the cost of planning, and the manpower and the time which will be required. Still more important, an understanding of the procedure will permit an administrator to understand the assumptions that have been built into the planning method and, thus, weaknesses in plans developed by the technique.

The manual is intended equally to serve the engineer-planner. In addition to general information, as valuable to him as to an administrator, the manual supplies details on use of the computer program. Diagrams and listings have been included to assist the user in checking data or making program modifications if and when that becomes necessary.

This manual is intended, too, to serve as a textbook for a series of workshops to be held across Canada. These workshops are to introduce planners to computer-aided planning of sludge disposal and to demonstrate the advantage of this approach.

1.2 How to use the Manual

The manual is divided into three parts:

1) general description of the planning process for sludge disposal and the computer contribution,
2) information details required for the computer program, and
3) discussion of the operations carried out in the program.

If you are an administrator supervising planning exercises, only the first part, a general discussion of planning and the use of computers will be pertinent. Chapters 2 and 4 form this part. They have been written to be read in sequence. Chapter 2 discusses the problem of sludge disposal planning on a regional scale, the benefits achieved by a comprehensive approach, and the role of the computer. The Niagara region serves as an example in this discussion. Chapter 3 examines the planning processes. Some of the steps in the process are discussed, particularly emphasizing how the information needed is obtained. Use of a computer to select a plan entails a "model"; Chapter 4 discusses the "model" assumed by the computer program.

The three chapters that we have suggested you read are short. Since their concepts are rather simple, the material can be covered in an hour or so of study. At the end of this time, you should know enough about the computer-aided technique to decide whether to use it in your region or municipality.

If your jurisdiction has decided to use the method, you may, as the administrator responsible, want to examine the second part, Chapters 5 to 7, once your study is underway. This will provide you with the background to communicate with the engineers carrying out the study. You will understand better what they are accomplishing and be in a better position to assist them in overcoming the problems encountered.

The second part of the manual, Chapters 5 to 7, has been written with the engineer-planner user in mind. As a user, however, we recommend that you review Chapters 2 and 4 quickly before you undertake the chapters following. Chapter 4, which describes the model employed in the computer program, should not be overlooked.

Chapter 6 and Appendix IV are the key sections for users. The former discusses the information needed for the computer and how it must be formulated mathematically for use in the program. Appendix IV organizes the information gathering by means of a questionnaire and then shows how this information is punched into the input data deck.

To see how the information is handled in a specific situation, Chapter 7 describes the application of the computer program to planning sludge disposal for the Regional Municipality of Niagara. The chapter also explains the planning information printed out by the computer for the Niagara Region. This information is interpreted at the end of the chapter.

Chapter 5 should be read after you have reviewed the general material in Chapters 2 to 4. It does not give instructions for employing the computer program, but rather describes the computing techniques used and how the program is put together. The chapter also discusses the options built into the program for versatility and ease of use.

Appendices V and VI need not be read by most users of the program. These have been included for persons with high-level skills in programming who may wish to have details to make modifications so that the program can be made more suitable for specific jobs. Frequently, when modifications are made, bugs arise; and to eliminate these it is often necessary to have a program flow chart and a listing. The listing is given in Appendix VI. As a user, you will not need to study these appendices unless data checking or program modification is required.

2. THE SLUDGE DISPOSAL PROBLEM

The problem and choices facing the engineer-planner in sludge disposal are the subjects of this chapter. We will consider, as well, the role a computer can play in the planning process. The process is described in Chapter 3 and the model for sludge disposal will be developed in Chapters 4 and 5. We will develop the discussion in this chapter using sludge disposal in the Regional Municipality of Niagara as an example. The computer program for planning sludge disposal was tested on cases suggested by this Regional Municipality during its development.

The regional municipality came into being in 1969 an as amalgamation of the Cities of St. Catharines, Welland, Thorold, Port Colborne and Niagara Falls. Included in the amalgamation were the smaller urban communities of Grimsby, Lincoln, Pelham, Fort Erie and Niagara-on-the-Lake, and two largely agricultrual townships, West Lincoln and Wainfleet. The population of the region is about 275,000 and about half of this is centred in the industrial belt taking in St. Catharines, Thorold and Welland. There is a broad range of industry in this belt and extensive farming is carried out between urban agglomerations and in the back townships away from the lakes. The population is expected to increase to about 350,000 in 1980 and about 450,000 by 1990.

2.1 Sludge Disposal in the Regional Municipality of Niagara

Before amalgamation into a regional municipality, the cities and most of the towns of the region had individual treatment plants. The nature of the plants is indicated in Table 1. Since the formation of the regional municipality, an attempt has been made to rationalize the waste treatment facilities. This is indicated to some extent in the table; for example, a group of small and, in some cases, antique treatment plants are being replaced in the next few years by a single plant serving the Grimsby area.

Table 1 indicates sludge production in 1972 in most of the plants operated by the regional municipality. Sludge handling facilities are also summarized. Digestion is generally used. Three of the four largest plants in the region are equipped with vacuum filters. The main Niagara Falls plant pumps digested sludge to a drying lagoon. This

TABLE 1. SEWAGE TREATMENT AND SLUDGE PRODUCTION - REGIONAL MUNICIPALITY OF NIAGARA+

Plant Location	Type	Design Flow	Actual Mean Flow	Sludge Production
Niagara Falls	Primary (Digestion, Vacuum Filter & Sludge Drying)	10.0 Imgd	7.6 Imgd	1.7 Imgd (3,183 cu/yd dried sludge)
Niagara Falls* (Chippawa)	Activated Sludge (Digestion)	0.3	0.46	0.25
Niagara-on-the-Lake	Lagoons	-	0.48	
Garden City Raceway	Lagoon	-	0.006	
St. Catharines (Port Dalhousie)	Primary (Going to Secondary) (Digestion, Vacuum Filter)	9.0	10.5	1.5
St. Catharines (Port Weller)	Activated Sludge (Digestion)	8.25	9.45	1.3
Welland	Primary (Digestion, Vaccum Filter, Drying Beds)	8.0	7.1	?
West Lincoln (Smithville)	Lagoon			
Grimsby**	Activated Sludge (Digestion)	0.375	Heavily overloaded	
Grimsby** (Beach)	Imhoff Tank		Heavily overloaded	
Lincoln** - Beamsville			Heavily overloaded	
Grimsby Biggar Lagoon	Lagoon			
Port Colborne (West side)	Activated Sludge (Digestion)		2.24	0.154
Port Colborne (East side)	Activated Sludge (Digestion)	0.85	1.32	0.094
Fort Erie	Primary (Digestion)	1.8	2.17	
Fort Erie (Crystal Beach)	Activated Sludge (Digestion)	0.85		0.014

+ 1972 Data

* Plant phased out

** To be replaced by Grimsby-Lincoln facility sludge is taken up when dry and windrowed on the plant property.

Sludge disposal prior to amalgamation was totally decentralized; each waste treatment plant arranged for disposal of only the sludge generated in its plant. This is hardly surprising since the plants were operated by independent jurisdictions. Even in regions of Canada where there is a single jurisdiction, decentralized disposal remains in frequent use. The City of Vancouver, for example, presently handles sludge from its three waste treatment plants in this way. The Lion's Gate plant disposes of sludge by pumping it into the Bay. The Richmond plant employs centrifugation followed by incineration, whereas the Iona Island plant uses a lagoon system. The decentralized system probably developed naturally because the waste treatment plants are widely separated geographically and were built at different times.

As indicated in Table 1, sludge disposal is handled quite differently in the various waste treatment plants serving the Niagara region. We will return to this problem further on because it poses a special problem for comprehensive planning.

The Niagara Falls plant dewaters sludge in a drying bed. The windrowed sludge is piled at the plant site, and can be removed by anyone in any amount with the city's permission. Compared with the rest of Canada, this drying of sludge by Niagara is typical. About 40% of the larger municipalities in Canada use drying beds (Viraraghavan, 1972). In Ontario, it is more common with plants of 7-8 mgd (eg. Guelph, Niagara Falls, Sarnia) than with plants of other sizes.

It is typical to remove sludge from drying beds while it is still very wet and to dry it further by windrowing. The object is to apply as much sludge per square foot per year as possible, to optimize the drainage characteristics of the beds, and the balance between application frequency and depth. Weather has an important influence on bed performance, especially in winter. In Canada, it might be typical to make six applications a year, each eight inches deep; in parts of the U.S.A. where freezing is not a problem it might be typical to make ten applications a year (Imhoff and Fair, 1956).

It is difficult to project the future for drying beds. They require labour and a demand for dried sludge. The labour input means the cost of disposal will rise from year to year. Demand requires nearby intensive commercial farming. However, Niagara Regional personnel are currently quite satisfied with the operation of this system.

Prior to formation of the Niagara Municipality, the Port Dalhousie and Welland plants used vacuum filters to produce a dewatered sludge. In each plant, different contractors were brought in to haul away this sludge. Digested activated sludge from the Port Weller, Port Colborne and Fort Erie facilities was picked up by these contractors and disposed of, usually through spreading on fallow or agricultural land. Arrangements for spreading sites were in the hands of the contractors.

Contracting for the disposal of sludge, as practiced in Niagara before regionalization, is widely used. It removes from the municipality a responsibility which is beset with technical problems and is often the source of the loudest complaints by environmental groups and home owners. Arranging for a disposal site for either spreading or landfill can often lead to political donnybrooks.

Sludge disposal practice in Niagara did not change until a few years after formation of the Regional Municipality. By 1972, the Regional Municipality had centralized its sludge disposal system. Instead of letting contracts for each plant in the region, a single five-year contract for sludge disposal was awarded to a private disposal service company for sludge removal from all the major plants with the exception of the Niagara Falls installation. That plant continues to use a drying bed - windrow system. The contractor established a holding lagoon in Lincoln and, according to Region officials, is spreading the sludge on either agricultural or fallow land. Trucks used for haulage are owned by the contractor and are garaged at one depot.

In line with the experience of other municipalities, contracting out sludge disposal has not been a totally satisfactory arrangement for the Niagara Municipality, even though a single contractor has assumed the disposal responsibility. The holding lagoon in Lincoln established by the contractor has been the subject of complaints by environmental groups, residents and now, town councils. The complaints must still be handled by the Municipality, although the responsibility for the operation is in the hands of the operator. Weather conditions appear to severely influence sludge spreading in Niagara. Since the contractor uses spreading for ultimate disposal, his ability to remove sludge depends on weather conditions, and the quantity of sludge withdrawn from the Region's digesters may vary from year to year. It has fallen on the Region to find ways of extending land spreading or finding disposal alternatives. Furthermore, municipal officials believe the contract price of 1.6¢/gallon of sludge removed is higher than it would cost the municipality if it were in a position to handle sludge disposal.

2.2 Future Disposal Plans for the Regional Municipality

Because of some dissatisfaction with the present methods of contracting out the disposal of sludge, the Regional Municipality retained a consultant to review its disposal problems. His report considered several methods as follows:

a) Landspreading on land owned or controlled by the Region.
b) Drying beds with windrowing and sale of dried sludge.
c) Use of existing vacuum filters in three plants followed by dumping as landfill or spreading on low quality agricultural lands.
d) Installation of a centrifuge in two of the Regional plants and disposal as in (c) above.
e) Flash drying the sludge to be sold or incinerated. This was considered impractical for the Region and, in addition, incineration is in opposition to the Ontario Ministry of the Environment's preference for land disposal.

For all alternatives, a centralized disposal system was assumed. Figure 1 shows the location of facilities which the Regional Municipality assumes will be operating during the next few years. Notice that in this projection, the group of small plants in the Grimsby-Lincoln area indicated in Table 1 have been replaced by a single plant and the smaller plants elsewhere in the region have been phased out. The land for spreading, or in the second alternative, the drying lagoon, was assumed to be available at a location equidistant from the Port Dalhousie-Port Weller, Welland and Niagara Falls pollution control plants (or about in the middle of Thorold). In the other two alternatives considered by the

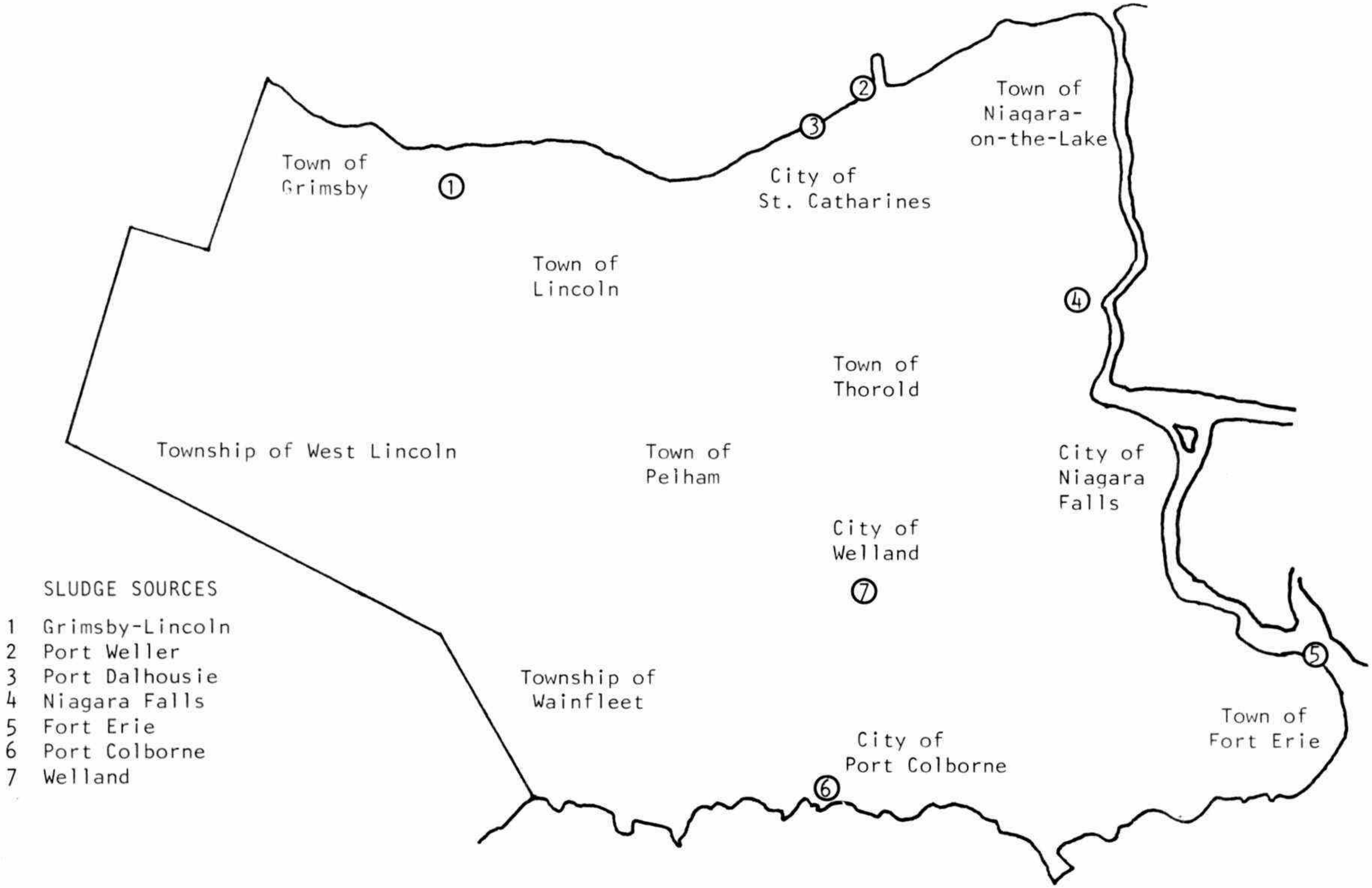

FIGURE 1. LOCATION OF TREATMENT PLANTS (SLUDGE SOURCES IN THE REGIONAL MUNICIPALITY OF NIAGARA).

consultant, all sludge produced in the region would be trucked to the existing vacuum filters or to the two centrifuges and then disposed of centrally.

Now it should be clear that the consultant considered in his study (which was not a planning study) only a miniscule number of the possibilities available. For example, Figure 1 shows that sludge must be trucked a considerable distance from Grimsby-Lincoln or Port Colborne to be disposed of by land spreading at a location near Thorold or dewatered by vacuum filters in the Port Dalhousie or Welland plants. Large acreages of agricultural land are located near both these sludge sources so certainly sludge disposal locally should be considered for Grimsby-Lincoln or Port Colborne. On the other hand, the Port Weller, Port Dalhousie, Welland and Niagara Falls plants are close enough together to consider a single central disposal facility to serve all four plants. Without much effort, you can suggest a great many alternatives: combinations of land spreading and use of vacuum filters, use of one vacuum filter (instead of all three) and land spreading, lagooning sludge in the central area and land spreading in the outer Grimsby-Lincoln and Port Colborne areas, and so on. It becomes a staggering task to evaluate all these alternatives.

Faced with the problem of considering the large number of alternatives, the engineer-planner can only fall back on looking at a fully decentralized sludge disposal system where disposal is planned for each plant as though it existed alone (even in this approach, a large number of alternatives must be dealt with), or he can evaluate single central facilities just as Niagara's consultant did. If he has a good deal of time or a number of assistants, the engineer-planner might evaluate a few of the obvious combinations as well as the fully centralized system.

As you will see in Chapter 7, when the computer-aided planning technique is applied to the Niagara Region, neither a fully centralized nor a fully decentralized disposal system gives the least cost. In 1975, the Regional Municipality should use four of the eight land spreading sites it is possible to acquire, and one of the lagoons. The existing vacuum filters probably should remain in mothballs. By 1985, however, increasing sludge production would make it attractive to activate one of the filters, although much of the sludge would still be land spread without dewatering.

2.3 Summary of the Planning Problem in Sludge Disposal

At this point, we can sum up our examination of sludge disposal in Niagara in the form of a few of what could be called truisms. These can be looked upon as the "problems" of planning or the "challenges", as you prefer.

First of all, the use of contractors does not absolve a municipality from responsibility for how its sewage sludge is handled. Complaints from home owners near disposal sites or along trucking routes still must be fielded by municipal officials, regardless of whether disposal facilities are operated by the municipality or by a contractor. Technical problems in disposal also fall to the municipality, mainly through default because contractors may not have the manpower or the facilities to resolve them.

Competition in the sludge haulage and disposal business is hardly ideal. A municipality not prepared to handle sludge disposal itself must accept disposal fees set by contractors. Costs cannot be controlled in this way. Thus, there is a trend developing whereby regions or municipalities are becoming more deeply involved in sludge disposal, even to the point of operating the disposal systems themselves.

In regions where there is fallow, agricultural or wooded land available, there are usually many technically feasible alternatives for sludge disposal. No universally applicable sludge disposal method has become proven by either economic forces or government decree. The circumstances in a region or municipality dictate the choice of alternatives.

Rarely will the extremes of a 100% decentralized or a centralized system of sludge disposal emerge as the economically optimal choice. Some mixture is usually best. Centralization leads to large facilities which generate economy of scale: facility cost per cubic yard of sludge will be less as the facility gets larger. Central facilities, on the other hand, mean longer transport routes and higher transport costs. Of course, decentralization keeps transport cost low because disposal facilities usually will be located near sludge sources. The sizes of facilities will be smaller, however, so the facility unit costs will rise. Lowest overall costs, the optimum from a strictly economic standpoint, often occur through a compromise between economy of scale and keeping transport distances reasonable.

Unfortunately, the compromise situation can be difficult to devise by simply looking at a map of the region or by other acts of simple reasoning. Once there are more than two sludge sources, two disposal alternatives, and a few possible locations for the disposal facilities, the number of possible disposal plans becomes alarmingly large. The number increases exponentially with the number of possible facilities. In this situation, computers must be used to compare all the possible plans and choose those yielding the least cost. This is the simple philosophy behind the computer-aided technique described in this manual.

There are other problems which are not well illustrated by the Niagara Region discussion. What should be the size of a region? This can often be answered by limiting a planning region to the geographical region under a single political jurisdiction. This is the case in Niagara where the planning region is the area within the boundaries of the Regional Municipality. There may be cases, however, where municipalities could lower costs by devising a joint disposal system. Thus, the size of the region for planning purposes cannot always be dismissed lightly.

What time period should be used for sludge disposal planning? Should the plan developed meet the disposal needs next year, a decade away or fifty years from now? What projections of sludge production, availability of disposal sites and relative costs of disposal alternatives can be made?

What are the criteria for an acceptable disposal plan? A disposal facility must not cause pollution itself; but how should noise and odour or nuisance be evaluated? The criterion easiest to apply is the one of cost. Theoretically, the plan adopted should cost no more than other alternatives. Yet jurisdictions which initiate planning studies are political bodies, so cost cannot be the only consideration in selecting a disposal system.

We will attempt to deal with these questions in the following chapters.

3. THE NATURE OF COMPUTER-AIDED PLANNING

In the previous chapters, the terms "comprehensive planning", "systematic planning" or "computer-aided planning" have been used. These terms will be explained in this chapter. The steps involved in solving the planning problem will be described one by one. Since the structure of planning is similar regardless of the application, many of the steps will be familiar to you. Other steps, necessary because a computer is used, will be new. The discussions of these steps will serve to introduce the thorough treatment of data organization contained in the latter chapters of this manual. Succeeding chapters are devoted entirely to the computer program used in the planning method.

3.1 Overview

3.1.1 Implications of computer use on the planning process

Planning of all types exhibits many common features. Computer-aided methods are not exceptions. All planning processes can be broken down into:

1) definition of the planning problem;
2) development of alternatives;
3) collection of data;
4) evaluation of the alternatives and selection of the optimal solutions; and,
5) testing or adoption of the solution and eventual further development.

These components, of course, will be recognized by planners and by anyone involved in solving technical problems. It is their special characteristics, derived from the use of a computer, that are of interest.

Computer use, first of all, permits a much more thorough consideration of the planning problem. A variety of aspects of the problem can be explored, such as the sensitivity of the best solutions found to the assumptions made, and how the solution changes with time. Many more alternatives can be examined; premature elimination of alternatives due to prescreening can be avoided. Prescreening, the conventional activity of eliminating alternatives for which detailed evaluation is "not worthwhile", assumes knowledge of what the solution will look like or how different parts of the system interact. If the system is complicated, valid solutions may be overlooked by prescreening.

To take advantage of the power of the computer, it is attractive to turn effort spared on the elimination of alternatives into data collection. Because of the exactitude offered by a computer, the precision of the data is significant as well as its quantity. It is this that is perhaps the most immediate and widely felt effect of computer use in planning: data collection becomes more important and time-consuming.

However, there are restrictions on the role of the computer in the planning method. As data must be processed by the computer in quantitative form, it cannot use qualitative information. All the data, including the descriptions of facility locations and transport routes, must be reduced to a numerical form which can be manipulated by the machine. Fortunately, this task is just a matter of learning a few conventions and then it is largely a mechanical operation.

The computer performs the evaluation of alternatives and thereby makes this step a small one in terms of time and effort for the engineer-planner. It is this potential sharp reduction of time and effort in evaluation, and the opportunity of doing a more thorough job, that makes computer use attractive for planning work.

Recapping briefly, the impact of computers on planning in terms of the structure at the beginning of this section is that step 2 - development of alternatives - can be broader and less exact, while step 3 - collection of data - demands more effort than would normally be expected without computer use. On the other hand, step 4 - evaluation of alternatives and selection of the optimal solution - becomes a very much easier task. When done competently, the net total effort would not be expected to be significantly different from that required by conventional methods; but more complex problems can be handled and better plans can be obtained.

3.1.2 Structure of the computer-aided planning process

Figure 2 is a block diagram showing the sequence of tasks that must be undertaken in planning a sludge disposal system. The tasks

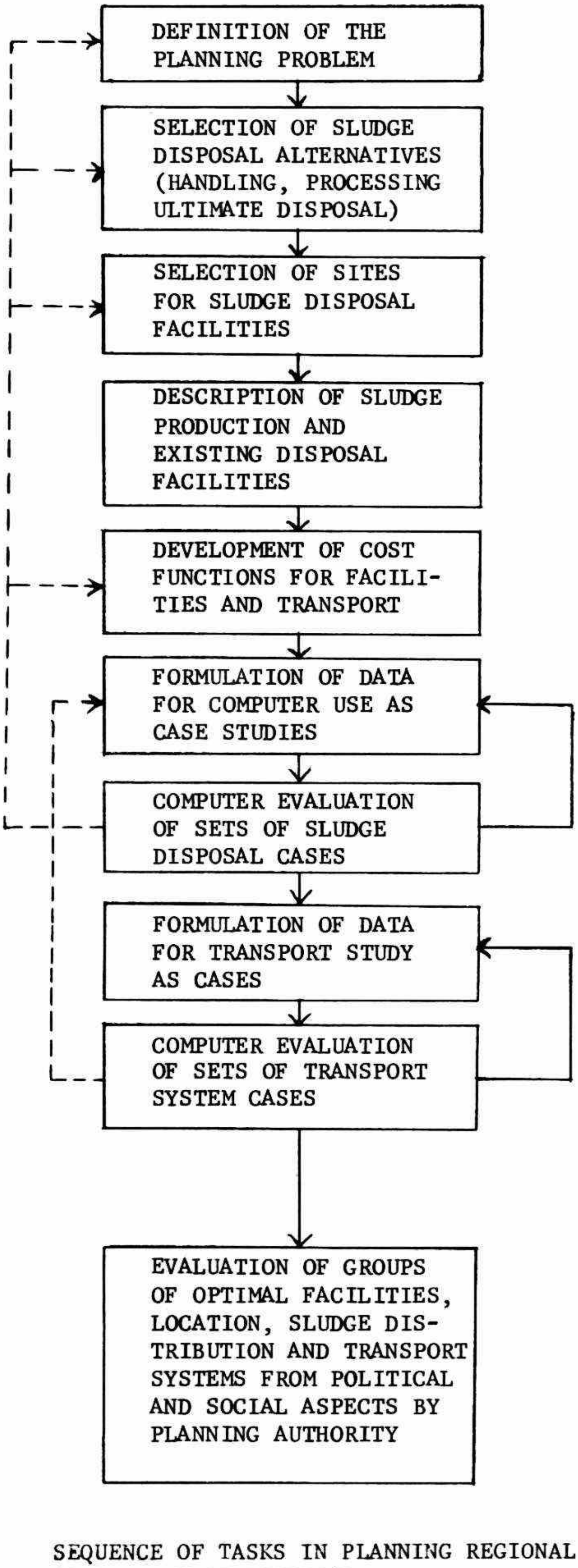
DEFINITION OF THE PLANNING PROBLEM
SELECTION OF SLUDGE DISPOSAL ALTERNATIVES (HANDLING, PROCESSING ULTIMATE DISPOSAL)
SELECTION OF SITES FOR SLUDGE DISPOSAL FACILITIES
DESCRIPTION OF SLUDGE PRODUCTION AND EXISTING DISPOSAL FACILITIES
DEVELOPMENT OF COST FUNCTIONS FOR FACILITIES AND TRANSPORT
FORMULATION OF DATA FOR COMPUTER USE AS CASE STUDIES
COMPUTER EVALUATION OF SETS OF SLUDGE DISPOSAL CASES
FORMULATION OF DATA FOR TRANSPORT STUDY AS CASES
COMPUTER EVALUATION OF SETS OF TRANSPORT SYSTEM CASES
EVALUATION OF GROUPS OF OPTIMAL FACILITIES, LOCATION, SLUDGE DISTRIBUTION AND TRANSPORT SYSTEMS FROM POLITICAL AND SOCIAL ASPECTS BY PLANNING AUTHORITY

FIGURE 2. SEQUENCE OF TASKS IN PLANNING REGIONAL SEWAGE SLUDGE DISPOSAL

are those introduced in the previous paragraphs. In the succeeding sections we will thoroughly examine the details of most of these tasks.

As may be expected, the compilation of data, including the construction of the computer model, entails the most work. The computer needs to be given several alternative sites for sludge disposal facilities of different types. These must be sites that exist or are really feasible. In order that the computer may find the best combination of alternative facilities, their best sizes and the best way to distribute sludge among these facilities from the sludge sources, it must be given cost coefficients that relate annual cost to facility size and to transport quantities. A great deal of space is devoted to the description of these tasks as they are not totally familiar to conventional planners.

The arrows in the figure show the sequencing which normally would be followed. The heavy line going in a backward direction from computer evaluation to formulation of data for use as case studies indicates that an iterative process is usually involved. It is because of this iterative nature that the method is described as a computer-aided rather than a computerized technique. The engineer-planner is not left out of the evaluation process. Instead of computerizing evaluation totally, which would mean handling the time changes in the system, formulating on optimal investment strategy, and automatic sensitivity analysis, what could be called a case approach has been chosen. A case is a set of data to produce a plan for a point in time for a certain set of assumptions about cost coefficients, facility size limits and boundaries of the planning region. Cases must be formulated by the engineer-planner. Human judgement involvement in the choice of cases to be examined greatly reduces the size of the computer program. It also makes the computer program easier to use and more versatile. For example, the case study approach is suitable for simple problems where an investment program is not required, as well as more complex ones in which the introduction of new facilities to meet rising sludge production and the schedule of investment are to be examined. It is where flow lines in Figure 2 lead upwards rather than downwards that "interactive" use of the computer programs occurs.

Two solid upward directed lines are shown in Figure 2. Both go from an "evaluation of the computer run" block to a "formulation of cases" block. Both represent user responses to computer results by calling for new cases to be run. The solid line indicates that we believe this "interaction" will be utilized routinely as part of the planning study. The uppermost return line shows use of the "interaction" for facility choice and location, while the bottom line shows it for planning the transport system. The latter is not treated in this manual; however, a computer program called SCHED1 has been developed, which is described briefly in Appendix VIII.

The dashed upward lines on the left side of Figure 2 suggest iterative processes which will occur much more rarely. For example, as a result of an analysis of the computer solutions to the planning problem, the engineer-planner may wish to redefine the problem that he is working on. The boundaries of the system might be changed or the time period for the study could be altered. This is suggested by the long dashed line going from the first "computer evaluation" block back to the top "definition" block. The engineer-planner might wish to consider different sets of sludge disposal alternatives. As a result of the costs developed for land spreading, it might seem worthwhile to him to consider using incineration. A dashed line, again, indicates this possibility.

Even though the program discussed in this manual was not written in an interactive mode* because of the quantity of its input and output, the planning technique illustrated in Figure 2 is basically an interactive one. Figure 3 summarizes the engineer-computer relationship.

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* The current meaning of an "interactive" computer program is a program which types requests for data at a time sharing terminal at which the data can then be entered by the user as input, which causes the program to run and type out the results and a request for new data. Our program was not designed to do this because its input and output constitute quite large data files. This does not mean, however, that the program cannot be used with one of the new "interactive" terminal systems (eg. IBM's CMS) which give the user the file manipulation power and execution speed of a computer operator. Of course, the program still would not actually type out requests for data, but anyone capable of using such a terminal would not need such prompting. Our use of the word "interactive" is different from either of these two meanings, as explained in the text.

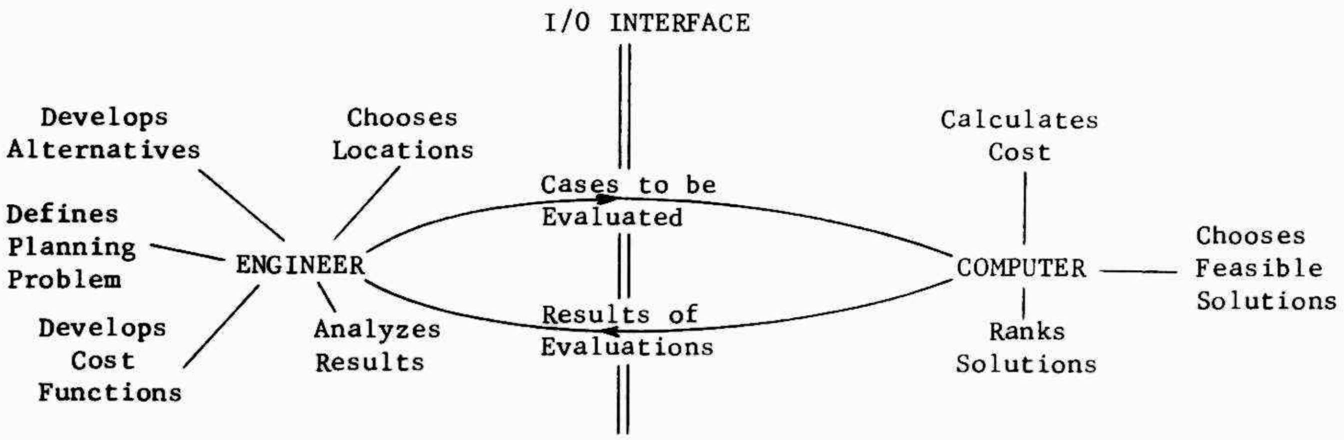

FIGURE 3. FUNCTIONS OF THE ENGINEER-PLANNER AND THE COMPUTER

The operation performed by the computer program will be discussed in Chapters 4 and 5. In the remainder of this chapter the other blocks shown in Figure 2 will be examined.

3.2 The Nature of Each Task

3.2.1 Definition of the planning problem

The first block in Figure 2 deals essentially with what is required in the solution of the planning problem. Often, this is described as the scope of the planning study or the terms of reference.

Considerations involved in defining a planning problem are shown diagrammatically in Figure 4. The starting point is the need for a sludge disposal plan. This need can arise in various ways. Its source is important because it delineates the scope of the planning study through the steps indicated in Figure 4. Perhaps a regional municipality might wish to establish a sludge disposal plan as part of an overall development plan. For a plan of this type, a fairly long time period, as much as 25 years might be required, but a high level of detail might not be necessary. It might be sufficient to indicate the type of facilities and roughly where these facilities could be located. On the other hand, the need for sludge disposal planning could be triggered by a specific question, such as what would happen to a regional system if a new town with an accompanying industrial district was created within the regional boundary. For this need, the time horizon might not be important; the situation after the new town had been constructed, at just one point in time, could be considered. However, in this case, a high degree of detail might be required. The regional municipality might wish to know the exact size of the facilities needed, their location, and their cost in order to bring these factors into the decision to approve the new town or not.

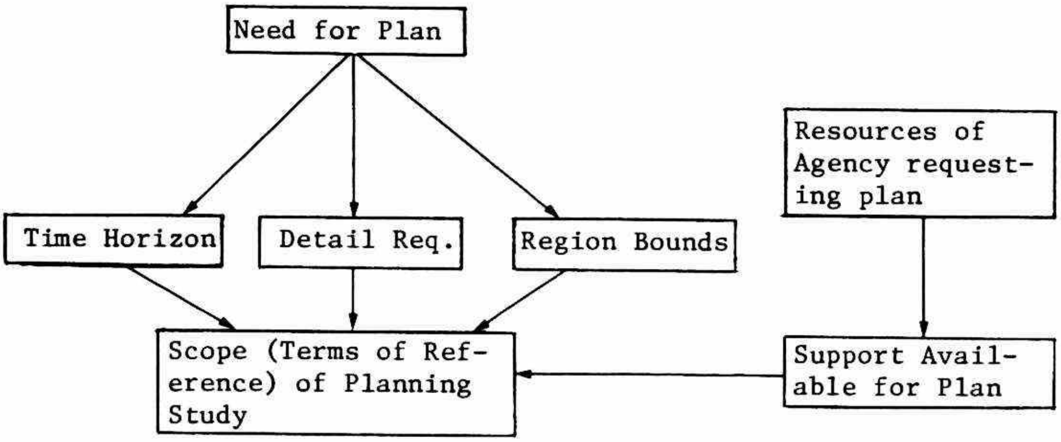
Need for Plan
Resources of Agency requesting plan
Time Horizon
Detail Req.
Region Bounds
Scope (Terms of Reference) of Planning Study
Support Available for Plan

FIGURE 4. CONSIDERATIONS IN DEFINING THE PLANNING PROBLEM

Figure 4 suggests the important considerations in setting the scope of a planning study. The term "time horizon" appears in the figure and has been referred to before. The term means the period of time the planning exercise is to plan for. A sludge disposal system designed for a time horizon of five years might look quite different from one designed to serve for 25 years.

In deciding upon a time horizon, a certain amount of realism must be maintained. The further one projects into the future, the more difficult it is to determine sludge volumes to be handled and guess at the government regulations or political considerations in force, interest rates and new technology. As mentioned earlier, the computer program allows for just one point in time and does not attempt to determine an optimum investment policy. An optimum investment policy nonetheless exists. For example, it may be cheaper for a municipality to buy property and construct oversized facilities for present sludge loads in anticipation of higher demand in future years than to purchase facilities which just meet current demands and expand these facilities as the need arises.

The second consideration is the bounds of the region. The best types of facilities used and indeed their locations will depend upon the distribution and sizes of sludge sources within the region. As the region encompassed by the planning study expands, the least cost combination of alternative facilities will change. Take incineration as a simple example. Incineration is a high cost disposal alternative for small sludge volumes, but cost per cubic yard of sludge processed drops quickly as sludge increases. If the region encompasses just a few small sources of sludge, incineration may not be part of the optimal combination of facilities; whereas if it expands to include more sources, incineration may become desirable. The dilemma of setting a regional boundary is rarely a serious one. In practice, it is difficult to establish cost sharing and operating agreements between two or more independent political jurisdictions (such as two municipalities). Consequently, the boundary is usually the geographical boundary of the jurisdiction that commissioned the planning exercise.

The third consideration in determining the scope is the detail required in a solution. For some planning purposes, it might be necessary to establish only if land spreading is to be used for sludge disposal. This might be the case if the sludge disposal planning is part of a land use planning exercise. The actual sites or fields to be used and the acreage required might not be necessary for this exercise. On the other hand, if the sludge disposal planning is carried out as part of a budget forecast, costs would be needed and this might entail determining not only the type of sludge disposal facilities required, but their size and location. The amount of detail desired contributes to determining the data collection effort and the number of cases which must be studied.

The last consideration in problem definition revolves around the conflict between what is desired and what is possible. The scope of a planning study must always be limited by the resources available to the sponsor, whether these be manpower or financial. Even with aid from federal and provincial governments for pollution control programs, the resources available to a small jurisdiction, such as a county, obviously will be much less than those available to Metropolitan Toronto. Even though the planning problem might be as difficult as Metro's, it is obvious that a county study must be much smaller in scope. This could mean that a county might have to be satisfied with a nonoptimal solution. Of course, it must not be overlooked that the cost of sludge disposal in a rural county is much less than in Metro. Therefore, the costs of a nonoptimal sludge disposal system will also be much less.

3.2.2 Development of planning alternatives

The use of a computer makes it possible to consider many more alternatives in sludge disposal planning than would be possible without the machine. It is important, therefore, to be sure that all realistic alternatives have been identified before going on to the solution phase. On the other hand, including "far out" alternatives, such as hydrogenation of sludge to produce a diesel oil, will rarely be worthwhile, particularly when a planning horizon is short, because it is unlikely that such alternatives would ever appear among the group of near optimal ones. Adding unproven and/or costly alternatives simply increases computing costs. The appropriate strategy is to devise as many alternatives as possible and then subject them to some preliminary screening before developing a list of facility types to be used by the computer.

Figure 5 shows these two functions. The figure also shows the factors involved in screening and the sources of information for establishing alternatives. The development of sludge disposal alternatives should not be a serious stumbling block in planning. Through publications and meetings, government agencies and the engineering profession itself provide substantial information on techniques for sludge disposal, result in practice, costs and other considerations.

Table 2 shows disposal alternatives worth considering in the east central regions of Canada stretching from the Great Lakes to the St. Lawrence basin. Little needs to be said about preliminary screening. Perhaps the most important factor to be considered is government guidelines. Ontario, at present, discourages incineration and favours land spreading. Thus, screening might eliminate incineration in studies where substantial agricultural or fallow land is available. Environmental considerations are certainly important. Open burning of sludge, which contributes to air pollution, might be screened out because solving one pollution problem should not create another one.

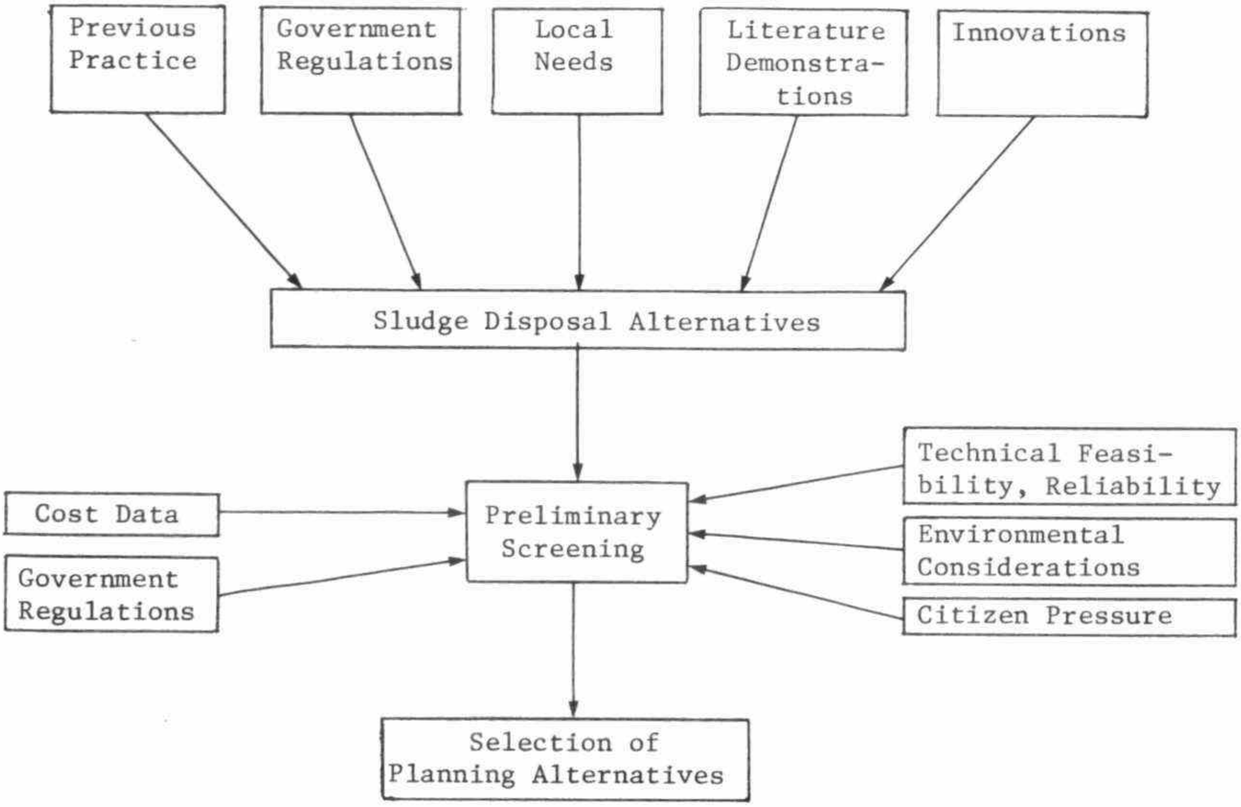
Previous Practice
Government Regulations
Local Needs
Literature Demonstrations
Innovations
Sludge Disposal Alternatives
Cost Data
Government Regulations
Preliminary Screening
Technical Feasibility, Reliability
Environmental Considerations
Citizen Pressure
Selection of Planning Alternatives

FIGURE 5. CONSIDERATIONS IN THE SELECTION OF SLUDGE DISPOSAL ALTERNATIVES TO BE CONSIDERED IN THE PLANNING STUDY

TABLE 2. POPULAR SLUDGE VOLUME REDUCTION AND DISPOSAL ALTERNATIVES

Land spreading
  - Raw or Digested Sludge*
  - Dewatered Sludge

Landfill
  - Dewatered Sludge
  - Digested Sludge
  - Deepwells

Drying Beds

Drying Lagoons

Composting

Incineration
  - with Refuse
  - Wet Air Oxidation

Dewatering
  - Thickening
  - Vacuum Filters
  - Centrifuges

Barging with Ocean or Lake Disposal

Conversion to Fertilizer

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* Not permitted in Ontario

3.2.3 Selection of sites for sludge disposal facilities

The selection of disposal alternatives discussed in the previous section rarely poses a problem to the engineer-planner; the difficult problem is the selection of possible sites at which facilities can be located. Location of any facility for handling wastes is always politically sensitive. In urban areas, no one wishes to have a waste disposal facility as a neighbor, whereas in rural regions opposition to accepting city wastes grows in response to such proposals. Although farmers have been accepting sludge on certain types of farm land for many years, few among them are sufficiently convinced of its value to pay for the sludge. In some areas, land spreading is considered a disposal service and a charge is made. Landfill or drying lagoons are vehemently opposed by rural residents.

Factors governing the choice of possible sites are basically three-fold, as shown in Figure 6. The first of these is the requirements of the disposal alternative being considered in the plan. For example, a site which will handle liquid sludge must be able to contain the sludge and any seepage that does occur should not enter aquifers. Possible sites should have easy access to all weather roads open to truck traffic. Finally, the high cost of land near urban areas (land thus attractive for sludge disposal) dictates that land already owned by municipalities be considered as sites to avoid the need to purchase property.

Figure 6 suggests that a large number of sites should be picked without detailed consideration of their suitability. After this has been done, a set of criteria can be applied to test each of the site selections. The J.F. MacLaren organization has devised a site selection for refuse system (solid waste) along the lines just mentioned*. A large number of possible sites is collected and systematically rated using a weighted grading system. This grading system uses weight factors to quantify qualitative information such as the pollution impact of the site, nuisance factors, accessibility to main roads, transport restrictions that might exist which would limit or control trucking in the site area, legal considerations such as zoning and site life. MacLaren's system is used as a screening technique to determine which sites should be included as possible disposal locations in a planning study which then uses just

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* See Appendix II.

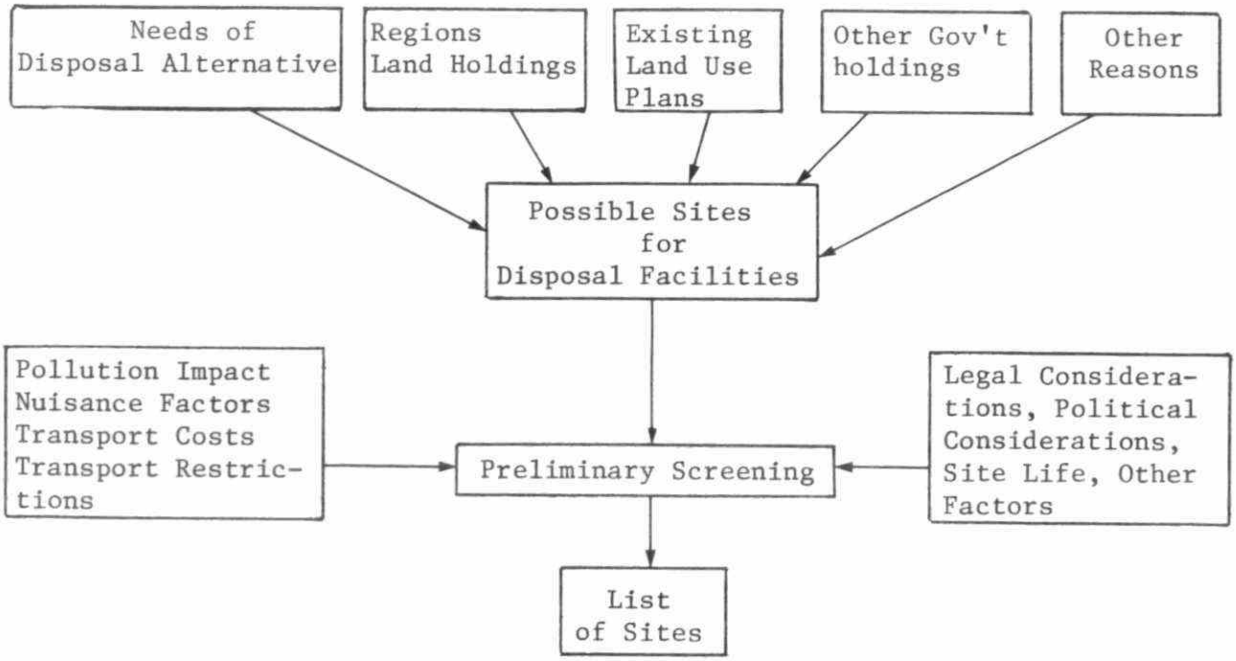

Needs of Disposal Alternative
Regions Land Holdings
Existing Land Use Plans
Other Gov't holdings
Other Reasons
Possible Sites for Disposal Facilities
Pollution Impact Nuisance Factors Transport Costs Transport Restrictions
Preliminary Screening
Legal Considerations, Political Considerations, Site Life, Other Factors
List of Sites

FIGURE 6. FACTORS IN CHOOSING A LIST OF POSSIBLE FACILITY SITES TO BE CONSIDERED IN THE COMPUTER-AIDED PLANNING PROCESS

economic considerations to select the optimal plan. The MacLaren system is applicable to disposal without a doubt. The MacLaren organization has kindly consented to let us reprint pertinent portions of a technical report describing its grading system. These excerpts are contained in Appendix II. The weighting factors assigned to the screening consideration will probably require some adjustment, depending on the disposal alternative. A site unacceptable for a landfill, for example, could be well suited for an incinerator.

Possible sites which pass a screening probably will not be unacceptable to the political authorities ultimately responsible for the selection of sludge disposal system. Because the information gathering can never be complete and political opposition often surfaces during the final selection process, any sites included in a computer selected plan must be re-examined. This is not the engineer-planner's responsibility, but it can lead to rejection of sites passing through the preliminary screening.

3.2.4 Forecasts of sludge production

Planning studies are concerned with the future so it is necessary to estimate the amount of sludge that must be handled by the disposal system in each year of the planning time period. Indeed, the value of the planning exercise depends on how accurately projections can be made.

Certainly, projections become less reliable the further into the future they are cast. A good deal of care must be taken in choosing the time horizon, particularly for sludge disposal, because technology, changing governmental regulations and variations in growth patterns all have a profound influence on the optimal disposal system. These factors are difficult to predict over a period longer than a decade.

The procedure for estimating sludge production at different sludge sources is shown schematically in Figure 7. Sources of estimates of population changes and distribution are also indicated in the Figure. Distribution information is useful because a region or a large municipality will be served by more than one treatment plant so there will be two or more sludge sources. Sludge production is tightly related to population. To estimate sludge production at a source, therefore, we must know the population (and industrial activity) served by each treatment plant. The first step in sludge production estimates is a projection of population distribution and industrial/commercial activity by geographical sections of a region. Projections of this type are difficult. It is a rather specialized field which will not be discussed further here. Sludge disposal planning usually comes at the end of regional planning studies. Population and industrial activity projections are required for other planning exercises, so that the needed projections are frequently available from regional development plans as indicated in Figure 7.

With population estimates available, sludge projections are rather easily calculated. The best means for this is to use municipal or regional data on sludge production in the past to calculate the sludge volume or weight (as dry solids) per year per capita. For example, the annual reports of the Public Works Department of the Regional Municipality of Niagara give data on the annual production of raw sludge and digested sludge. For a two-year period (1972, 1973) the per capita annual sludge production ranged from 27 to 48 pounds per capita per year from three primary treatment plants in the region (see Table 1); the average production was 38 pounds per capita per year. For secondary treatment plants, the production ranged from 9 to 24, with a mean of 15 pounds per capita per year.

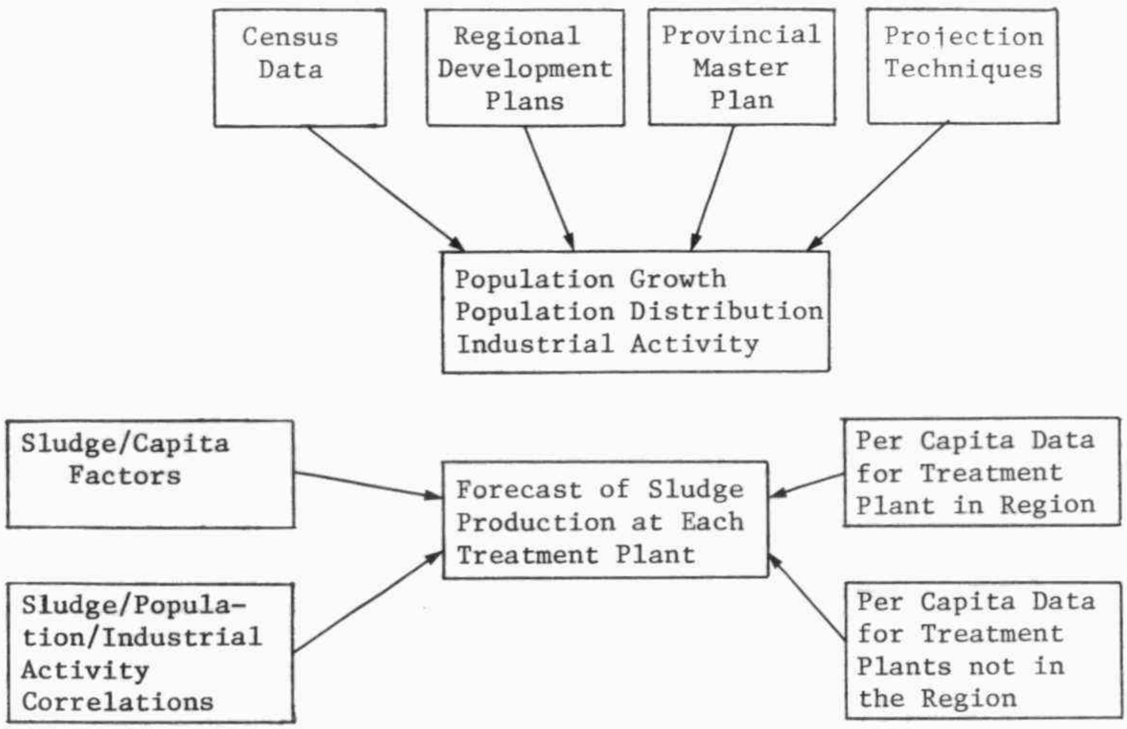

Census Data
Regional Development Plans
Provincial Master Plan
Projection Techniques
Population Growth
Population Distribution
Industrial Activity
Sludge/Capita Factors
Forecast of Sludge Production at Each Treatment Plant
Per Capita Data for Treatment Plant in Region
Sludge/Population/Industrial Activity Correlations
Per Capita Data for Treatment Plants not in the Region

FIGURE 7. METHOD OF FORECASTING SLUDGE PRODUCTION

Alternatively, data from other regions can be used. It is usually worthwhile checking per capita figures from regional data against other data sources. Per capita sludge production for the Niagara region secondary plants averages less than that for the primary plants. The "rule of thumb" is that sludge from conventional activated sludge plants should be about 50% greater than from a primary plant. Thus, the regional data are questionable. Table 3 summarizes 1972 data for 11 secondary waste treatment plants. The mean for these plants is 58 pounds per capita per year. It is interesting that this is just about 50% greater than per capita production for the Niagara primary plants. Obviously the higher figure should be used in any planning study for the Niagara region.

Another check on per capita data calculated for a region is textbook figures for sludge production. For example, primary treatment commonly produces 1,000 pounds of sludge (or 0.6 cubic yards) for each million gallons of flow handled, while secondary treatment adds an additional 600 pounds or 0.4 cubic yards per million gallons.

TABLE 3. 1972 PER CAPITA DIGESTED SLUDGE PRODUCTION IN ONTARIO SECONDARY TREATMENT PLANTS OPERATED BY THE ONTARIO MINISTRY OF THE ENVIRONMENT.*

Municipality	1972 Population	% Solids	lb/Capita/Year
Belleville	34,812	6.6	70.1
Brampton/Ching.	42,804	20.0	79.4
Brantford	61,445	4.3	56.7
Coniston	33,671	5.1	96.9
Galt	37,633	3.4	37.0
Kitchener	110,000	2.3	46.0
North Bay	46,409	4.5	54.2
Simcoe	10,455	2.1	30.1
Stratford	24,048	4.3	44.7
Wallaceburg	10,292	7.5	87.4
Waterloo	36,500	2.7	67.9
Mean		4.0	58.4

* Reference: "Operating Summary, 1972, Water Pollution Control". Report of the Project Operations Branch, Ontario Ministry of the Environment, Toronto, 1973.

Addition of chemicals for nutrient removal must be allowed for as the above figures do not allow for the extra sludge generated thereby. Estimates are that sludge production will increase by between 5% and 50% from chemicals addition, depending on the type of plant and the chemical.

The existing sludge disposal facilities in a region must be taken into account in planning. Usually, these facilities will be found in the least cost disposal system because their use entails no capital outlays. In some cases, it will be cheaper to abandon some of these facilities, especially those showing a high operating cost. In a preliminary study made of the Regional Municipality of Niagara, for example, it was found that at the beginning of the planning period, it would be cheaper not to operate existing vacuum filters where sludge was to be spread on the land or where wet sludge could be taken by a landfill site. However, by the end of the period, the large amount of sludge to be handled would force the use of these facilities. What is needed for an existing facility in the computer-aided planning technique are the location, size limit and operating cost. The latter should be known as a function of operating level. In addition, if an existing facility would have a significant salvage or sale value, if it is not retired, this should be known.

3.2.5 Development of cost functions

Once a set of possible locations for sludge disposal facilities has been established which seem to meet environmental, legal and political considerations, the choice of a system of sludge disposal is reduced to the problem of selecting the least cost combination of facilities for the job. Before a search for this combination can be undertaken, cost of disposal facilities, operating and sludge transport cost information must be available. Of course, this information must be formulated in a particular way for use by the computer. This will be dealt with in Chapters 5 and 6. At this point we are concerned with only how this information can be gathered.

3.2.5.1 Facility capital cost. Figure 8 suggests schematically the sources of capital cost information. It also dicates how this information is manipulated into a form usable by the computer program. Probably the most reliable source of capital cost is records of purchases made by the region of equipment, such as vacuum filters or land, where the land is similar in location and character to that under consideration for a sludge disposal facility. Only slightly less useful are purchase records from neighboring jurisdictions. Some caution is needed in the use of these data. The nature of the equipment may differ from purchase to purchase. In some cases, ancillary equipment may have been obtained and its cost included in the price. Corrections must be made. Cost, of course, must be correct to a common cost index. The EPA index for the cost of pollution control equipment is probably the best one to use, although the appropriate ENR index is also suitable.

The major problem in using purchase costs is that what is needed are the installed costs. Sometimes this can be obtained from contractors' bills, but all too often contractor billings cover work on more than one unit so that it is difficult to determine costs assignable to, say, preparation of a sludge drying lagoon. In cases where contractor costs are usable, the sum of this cost plus the purchase price gives the installed cost. Installation costs depend on local conditions to some extent, so factors used to translate purchase to installed costs are not always reliable.

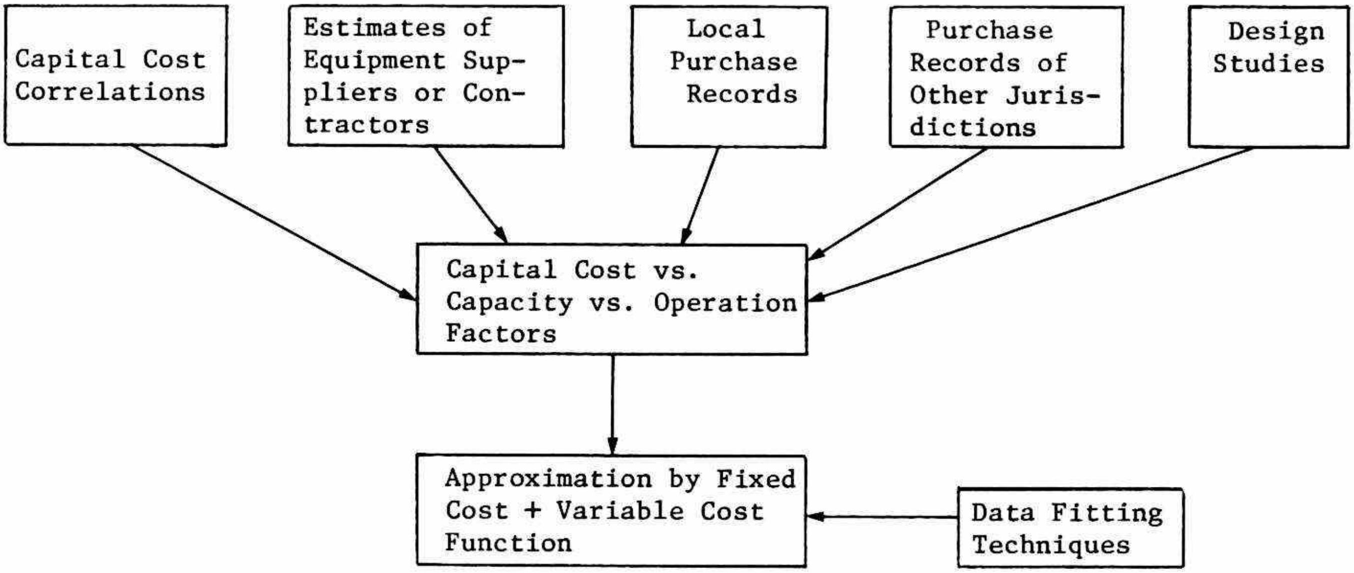

Capital Cost Correlations
Estimates of Equipment Suppliers or Contractors
Local Purchase Records
Purchase Records of Other Jurisdictions
Design Studies
Capital Cost vs. Capacity vs. Operation Factors
Approximation by Fixed Cost + Variable Cost Function
Data Fitting Techniques

FIGURE 8. SOURCES AND MANIPULATION OF CAPITAL COST DATA

Where data from records are not sufficient, it is possible to develop costs through design studies and estimates or preferably quotations by equipment suppliers. In the case of landfills or lagoons, contractor estimates can be used.

However the costs are arrived at, the objective is a plot of cost versus facility size, with other factors as parameters. As is indicated in Figure 8, these curves must be fitted by a straight line (so as to intersect the cost curve in at least two points) to give the fixed charge plus marginal cost approximation used in the ALL02 computer program. A least squares procedure could be used for fitting.

The work needed to create cost versus size curves from scratch can be considerable. It may be avoided without an all too severe reliability penalty by using existing cost correlations. In the course of the project leading to the preparation of this manual, capital (equivalent annual) cost correlations were undertaken using as a basis the exhaustive survey and design studies performed by Black and Veatch, Consulting Engineers for the U.S. Environmental Protection Agency (Patterson and Banker,

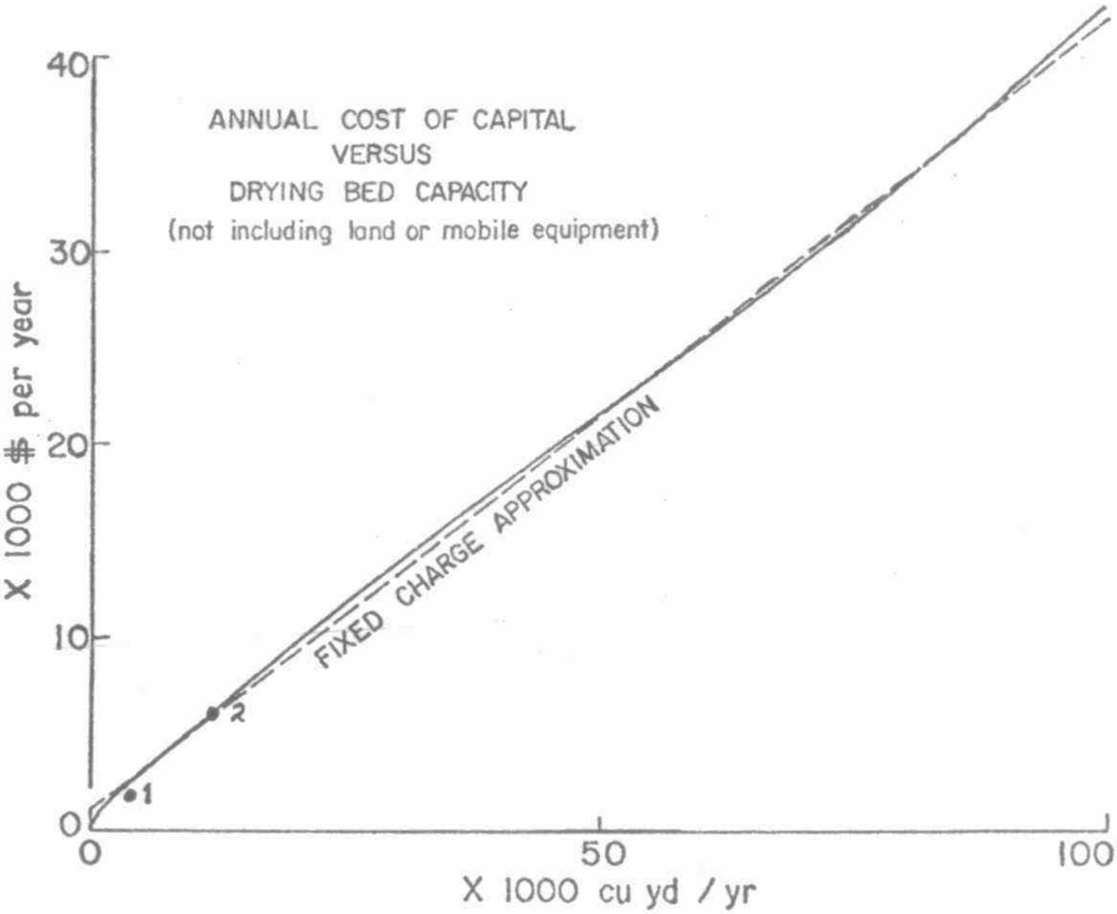


FIGURE 9. CAPITAL COST OF DRYING BEDS VERSUS SIZE

Note: 1 = Cavan Twp. (Obtained from Ministry of the Environment)
2 = Oshawa (Obtained from City)

1971). These correlations, for lagoons, holding tanks (or basins), vacuum filters, centrifuges and multiple hearth incinerators, are contained in Appendix III. The assumptions and the development of these correlations are discussed exhaustively in the Appendix. Figure 9 reproduces a capital cost (annual) correlation for drying beds from Appendix III. The data points are based on project costs for two Ontario locations. The straight line approximation is also shown. It can be seen that it represents the data quite well. This cost correlation, as well as all others in Appendix III, assumes an Autumn, 1973 cost datum.

Although the cost correlations in Appendix III are convenient and may save much labour, their estimated accuracy is about ± 20%. In some cases, cost differences of this magnitude could be sufficient to influence the choice of a sludge disposal system. Sensitivity studies, exploring the effect of cost used, should be undertaken as part of the planning exercise.

3.2.5.2 Facility operating and maintenance cost. Operational costs, apart from the annual capital charges, are important for all sludge disposal methods. Figure 10 is a companion schematic to the one previously given and suggests sources of operating cost data and manipulation of these data to forms suitable for computer use.

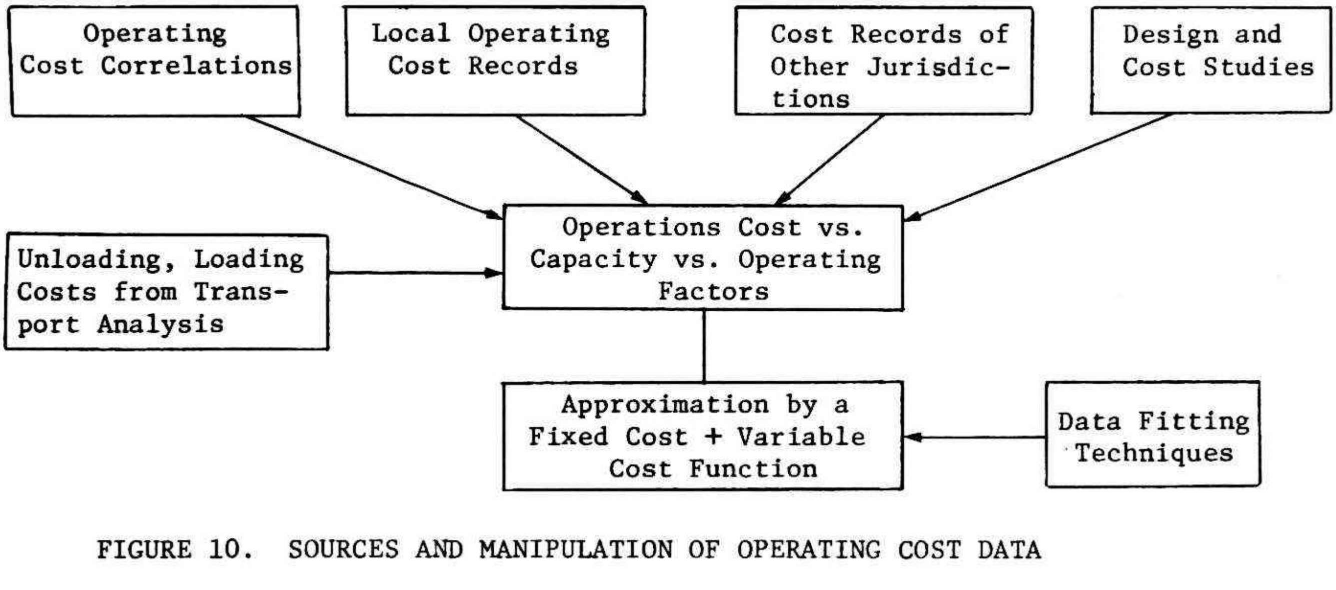

Operating Cost Correlations
Local Operating Cost Records
Cost Records of Other Jurisdictions
Design and Cost Studies
Unloading, Loading Costs from Transport Analysis
Operations Cost vs. Capacity vs. Operating Factors
Approximation by a Fixed Cost + Variable Cost Function
Data Fitting Techniques

FIGURE 10. SOURCES AND MANIPULATION OF OPERATING COST DATA

The best source of operating costs is the local records of the region. However, problems can be encountered using these data. Vacuum filters or centrifuges are located in treatment plants so their operating costs are often lumped with waste treatment costs. They must be broken out of the lumped costs. Where local records are inadequate or nonexistent, records of nearby jurisdictions may be useful. Actual operating cost data must be corrected for the appropriate wage rates so a breakdown into labour and overhead, and supplies and materials should be available.

In place of operating cost data from records, or as a supplement, hypothetical studies of costs can be made. These assume manpower and supplies needed and estimate maintenance often as a percentage of the annual cost of capital.

When operating costs are taken from records or estimated, cost contributions from loading and unloading sludge can be added, as an alternative to having them charged against transport. This will be discussed further in a later section.

As for capital cost, the objective is a plot of O & M cost versus annual quantity of sludge handled. The resulting curve must be fitted by a straight line so as to divide the cost into fixed and variable (facility size) contributions (see Chapter 4).

Operating cost correlations can be used in place of estimation from records. Appendix III provides correlations for the disposal methods indicated previously in the form of fixed plus marginal costs. The correlations are based on separate correlations for operating labour, maintenance labour and materials and supplies taken from the Black and Veatch study. Assumptions made and the development of the correlations are discussed in the Appendix. The cost base is Toronto, 1973. Since the cost coefficients in the Appendix are broken down into three categories used by Black and Veatch, corrections for labour rates etc. can be made. Although not shown in the Appendix, the fixed charge cost functions approximate the Black and Veatch curves quite well.

A check on the use of these correlations with 1973 operating data for the city of London, Ontario gave agreement to better than 15% for vacuum filters, but was seriously in error and low for incineration.

It would be useful, therefore, to undertake sensitivity studies of the planning solution to see how it is affected by the operating costs used.

3.2.5.3 Sludge transport cost. Transport cost information required for a planning study. In Figure 11, sources of cost data are shown. It is best, whenever possible, to use costs actually experienced by the region or municipality. If the region itself runs the sludge haulage operation, municipal records can be used to construct transport cost correlations. A considerable effort is necessary to analyse any records. The objective is a cost per unit quantity for each potential transport task in the computer model. A transport task is the movement of sludge between a particular "source-facility" or "facility-facility" pair. Preferably, linear correlations valid for several transport tasks should be found for this unit cost versus distance or trip time. Such correlations, which we call haulage formulas, are very helpful in setting up the data and in sensitivity studies.

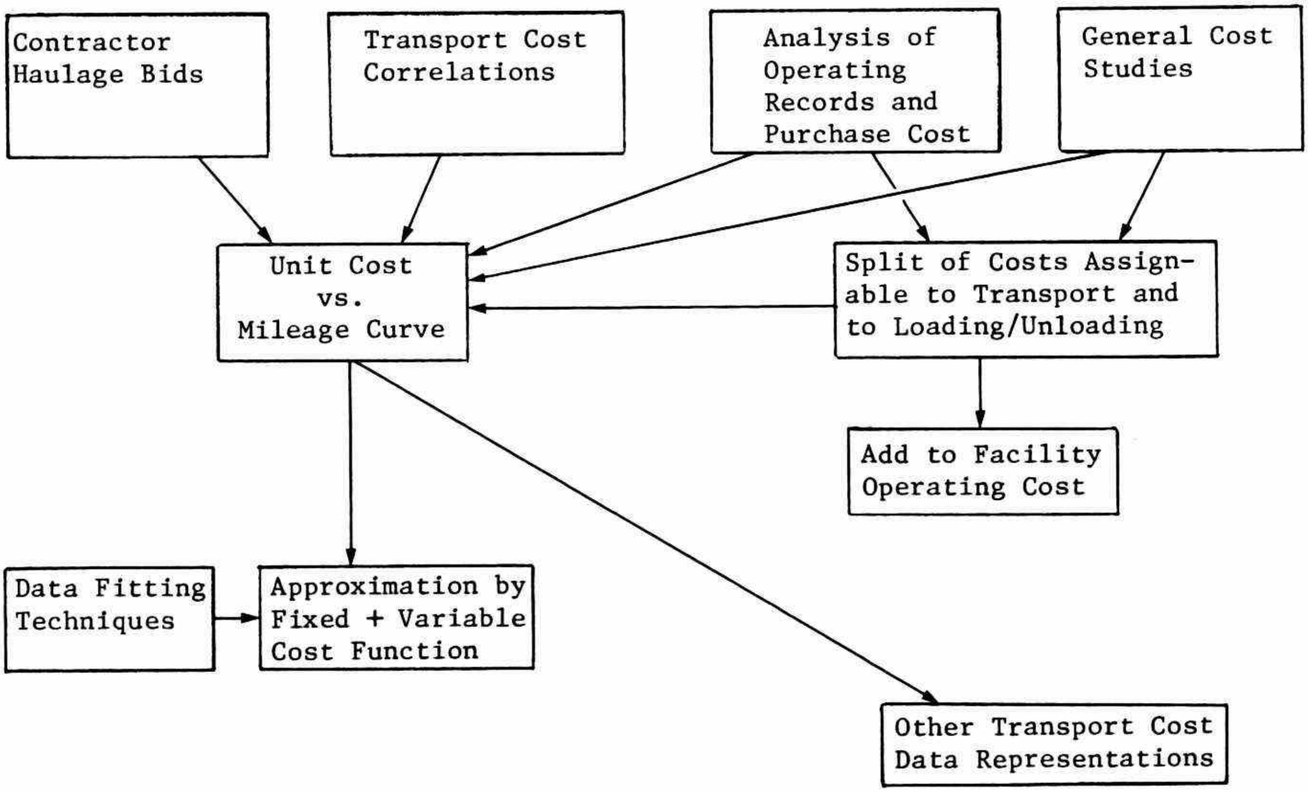

Contractor Haulage Bids
Transport Cost Correlations
Analysis of Operating Records and Purchase Cost
General Cost Studies
Unit Cost vs. Mileage Curve
Split of Costs Assignable to Transport and to Loading/Unloading
Add to Facility Operating Cost
Data Fitting Techniques
Approximation by Fixed + Variable Cost Function
Other Transport Cost Data Representations

FIGURE 11. SOURCES AND DEVELOPMENT OF TRANSPORT COSTS

Overall transport costs, such as for truck fleet size and management, are not easily taken into account at this stage by saying some part of it is a component of the unit cost in a certain transport task. It is better to assume a certain complement of transport equipment and management in order to obtain unit costs that are accurate over a good range of quantity. The unit costs then represent primarily wages and operating and maintenance. When a solution has been found, it can be used to check the assumption on fleet size, etc. as described in section 3.3. Alternatively, costs such as truck capital can be represented by the contribution of "hourly rental fees" to unit costs. When the equipment is not really rented, however, this contribution is difficult to ascertain.

To strengthen any correlation of unit cost versus trip length or distance obtained by means of local operating and purchase records, the records of other communities can be analysed to break out unit costs for various transport tasks of different trip lengths or distances.

If, on the other hand, sludge haulage is carried out under contract, the information available is bid price, usually as dollars per gallon or cubic yard. If the disposal facilities used by the contractor are known, unit cost correlations against distance perhaps can be developed. Usefulness of bid prices is limited because of factors other than haulage distance and sludge consistency which enter into costs. Disposal by the contractor includes burdens (overheads) which may be shared with other contracts held, and the degree of competition probably influences bid price as well. Much must be known about the contractor's operation before the cost or cost correlation obtained from bid data can be accepted. Although shown as a source in Figure 11, bid prices are probably better suited as checks on cost or correlations from other sources.

An alternative to establishing costs from records is to obtain them by a hypothetical study based on purchasing a fleet of trucks for haulage and using information on operator and repair, manpower, operating and maintenance costs.

Where records are used for establishing transport cost, cost obtained may be corrected for unloading/loading costs. This seems advisable because sludge haulage trucks are frequently used for land spreading. This function should not be charged against transport if it is desired that haulage formulas be independent of the disposal facilities. This is just a matter of convenience. Similarly, loading and unloading of dewatered sludge may cost more than un-dewatered sludges. Extra costs should be charged against the dewatering plant or against landfill. Separating these costs would require time studies to work out the portion of haulage trips spent in loading and unloading sludge. Costs would be split between facility and transport on the basis of time spent for loading and unloading and actual haulage, respectively.

Figure 11 shows correlations as an alternative for unit costs. During the development work on the computer-aided technique, an investigation of sludge transport cost was undertaken which is reported in Appendix III. This investigation found a great deal of scatter in transport costs which we believe reflects the size of the contracts and competition. Unit cost correlations were prepared:

Dewatered Sludge:

$$C/Q = 1.0081 + 0.1527D$$

Digested, but Undewatered Sludge - Land spreading:

$$C/Q = 1.2308 + 0.0725D - 0.10445 + 0.0011A$$

- Sludges not land spread:

$$C/Q = 0.3149 + 0.0140D + 0.1545S$$

Combining the last two correlations and omitting the solids concentration dependency gives an overall correlation for undewatered sludge:

$$C/Q = 0.9253 + 0.0592D$$

In all these correlations, C/Q is the unit cost (C = cost in dollars, Q = quantity of sludge transported in cubic yards). D is the one-way distance in miles, S is the sludge concentration in weight percent and A is the acreage at the land spreading site.

The unit cost correlation for dewatered sludge uses only four data points and represents these points quite well. The fit is much poorer for the liquid sludge; correlation coefficients are about 0.5. Introducing a term for Q, sludge quantity, on the right side and using only C on the left side would improve the correlation considerably, but since the unit cost would then depend on the sludge quantity, it could not be used by the computer program ALL02. Indeed, only the correlations for liquid sludge in terms of D can be used because S (sludge concentration) and A (acreage) are not included in the computer model.

Further details of the transport cost correlations are discussed in Appendix III.

3.2.6 Formulation of study cases

In our discussion we have been proceeding through Figure 2, showing the overall sequence of tasks in a disposal planning study. We have been concerned up to this point with the development of data to be used in the economic assessment of alternative facilities and locations for sludge disposal. From now on we will deal with the use of the computer program.

As discussed in the beginning of this chapter, the planning method is basically an interactive one involving user and computer. The mechanism for this is by case studies. However, we are not using the term "case study" in the conventional sense of a fixed system which one postulates in order to calculate a total cost. Rather, we wish to imply only fixed limits within which the system can vary and a fixed relationship of cost to the system as the computer varies it. The absence of specificity in case studies makes them very simple to use. The engineer-planner formulates a case to be fed to the computer. This case represents a point in time, an assumed set of cost coefficients, a set of potential facilities and locations to be examined. A potential facility is just a facility which, due to its being included in the case, is potentially in the lowest cost combination of facilities the computer will find for the case. It may be existing or just a feasible alternative; different potential facilities may be included in a case in order to represent alternative types of facilities at the same site or the same facilities at alternative sites. From the computer output from different cases, best combinations of facilities become visible as a function of the cost assumptions or the point in time horizon. These best combinations in turn suggest new cases to be formulated. Through a series of cases, thus, an appropriate solution to the planning problem can be developed. Although an approach such as this is strongly heuristic, and an absolute optimum is not assured, we are confident that, through intelligent use of the method, combinations of facilities which are virtually optimal for the planning job can be obtained. Figure 12 shows how this part of the work is structured.

The first step involves case formulation. This requires, first of all, information on the types of facilities, lists of locations with the type of facility for each location, sludge sources and annual sludge production at each, and costs. All of this information is put in a form compatible with the computer program as discussed in Appendix IV. To formulate a case, you would specify the number of potential facilities of each type to be considered and the location of each potential facility. A size limit for a facility at a site is assigned if limitations on capacity must be enforced. Where other limitations arise, such as nitrates added to the soil, these must be interpreted in terms of volume capacities. The cost functions used in a case are chosen by the user so they can be intentionally altered in other cases as a means of exploring sensitivity of the best combination of facilities to the cost functions. The number of sludge sources reflect the size of the region and sludge production used establishes the point in the time horizon considered. These, too, are elements of a case.

The next step indicated in Figure 12 is the formulation of the computer run and printout control parameters. This is discussed further in Chapter 6 and Appendix IV. Control parameters are required because the planning program ALL02 has been written with versatility in mind.

One aspect of the planning job rarely mentioned is that the "solution" obtained must be presented to the ultimate decision-making authority, a political body, in such a way as to assist the authority in making its decision. Required from the program then, in addition to the "optimal" plan, are the "near-optimal" ones. These would be "solutions" which would be close enough to the optimal one to be attractive economically, but might offer advantages with respect to political or environmental criteria. In addition, the cost of the present disposal system is needed, worked out using the same cost data employed in the planning study. Further, the cost of any other specific system or, for that matter, random nonoptimal solutions, are needed to properly assess the cost advantages offered by the optimal or near-optimal plans.

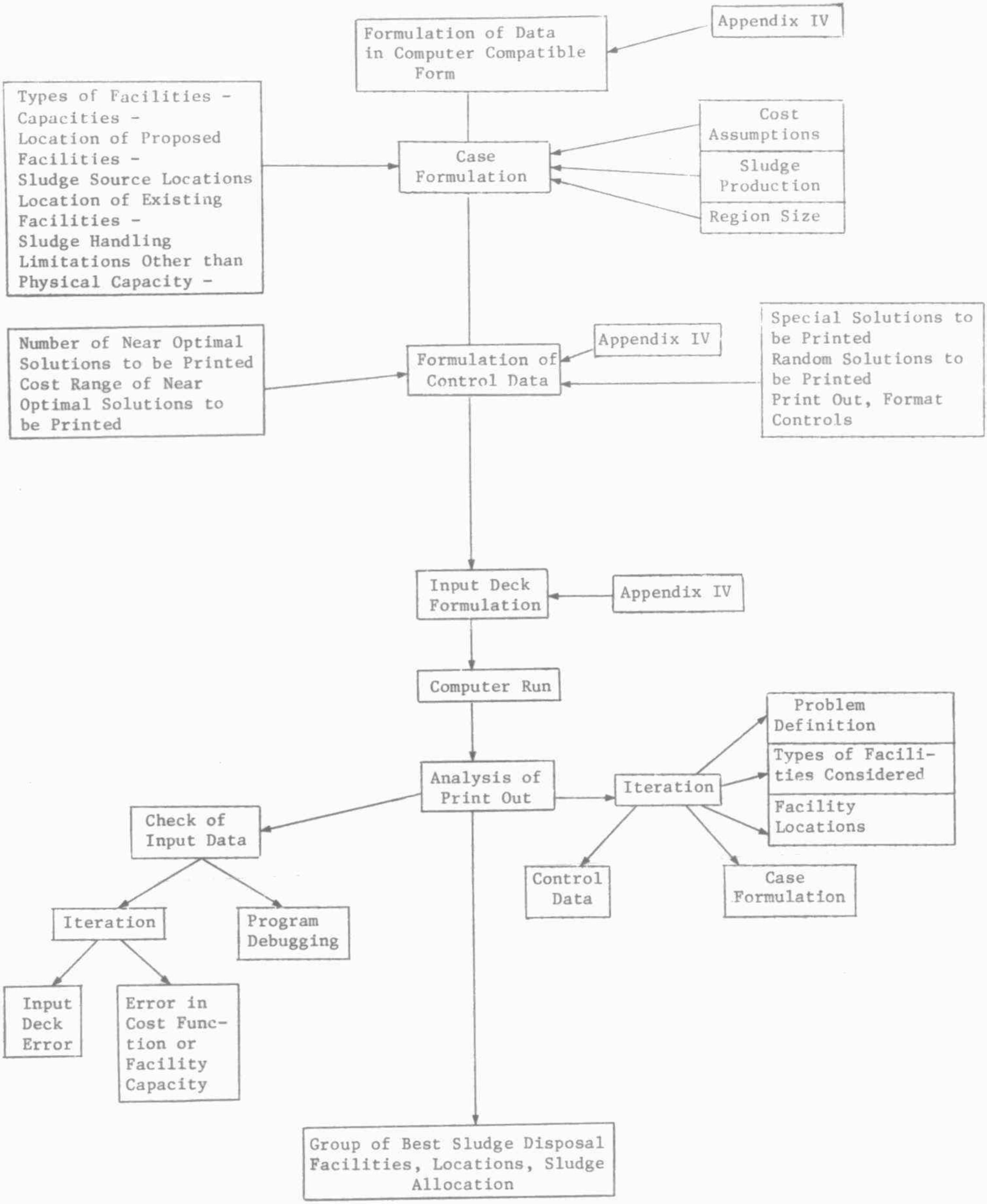

Formulation of Data in Computer Compatible Form
Appendix IV
Types of Facilities - Capacities - Location of Proposed Facilities - Sludge Source Locations Location of Existing Facilities - Sludge Handling Limitations Other than Physical Capacity -
Case Formulation
Cost Assumptions
Sludge Production
Region Size
Number of Near Optimal Solutions to be Printed Cost Range of Near Optimal Solutions to be Printed
Formulation of Control Data
Appendix IV
Special Solutions to be Printed Random Solutions to be Printed Print Out, Format Controls
Input Deck Formulation
Appendix IV
Computer Run
Analysis of Print Out
Check of Input Data
Iteration
Program Debugging
Input Deck Error
Error in Cost Function or Facility Capacity
Iteration
Problem Definition
Types of Facilities Considered
Facility Locations
Control Data
Case Formulation
Group of Best Sludge Disposal Facilities, Locations, Sludge Allocation

FIGURE 12. STRUCTURE OF CASE FORMULATION AND USE OF THE ALLO2 PROGRAM

Through the control parameters, you can choose to examine the near-optimal solutions by causing ALL02 to print out either a certain number of near-optimal solutions or all the solutions lying within a cost increment above the least cost solution. This certain number or cost increment (or bound) is specified by the user. As discussed further in Chapter 6, it is possible to ask the computer to examine specific solutions. For example, it may be of interest to consider a single centralized solution, as discussed in the previous chapter, or the disposal method now used, and compare either to the "optimal" plan. The object would be to establish the magnitude of cost savings that can be achieved by the planning technique. A similar grasp of the cost picture and the advantages of the optimal solutions is obtained by asking the ALL02 program to print out solutions at intervals of, say, every 1000 configurations of the disposal system examined, regardless of whether or not the "solution" is near-optimal. Comparison of these arbitrary disposal systems with those which show the lowest cost provides the useful overview of cost mentioned above.

Continuing with Figure 12, the next step is the actual formulation of the input deck and the computer run. Several cases may be included in one run. A number of options are available after the computer run has been completed. Certainly a check of the printout is necessary to see if the answers obtained are meaningful. To assist this operation, the printout contains portions of the input data in a way to assist in determining whether the input was correct or not. For example, the cost function data should be examined to ensure they have been properly formulated and are realistic.

A single computer run will seldom be enough. After the first run, the group of near-optimal solutions (combinations of facilities) printed out would be examined for the cost variation. If the variation is small or if the cost found is small compared to the least cost solution, it may be useful to expand the cost bound or the number of solutions considered so as to establish the point at which the costs begin to increase rapidly. Alternatively, it may be useful to run the system asking for specific configurations which might seem to be obvious choices by inspection, but which did not appear in the group of optimal solutions. This would allow what might be called "common sense judgment" to be tested against the computer program.

Once the full information for a case has been developed, a new case can be formulated to examine another point in time, a different region size or perhaps the sensitivity of the disposal plan to the cost information. Often an analysis of the printout from the previous case will suggest possible new cases to explore. It is this formulation and reformulation of cases that we referred to as the interactive portion of the planning process at the beginning of this chapter.

3.3 Study of the Transport System

Sludge disposal planning encompasses choice of sludge disposal facility types, size and location of facilities and specification of a transport system to move sludge from the treatment plant or sludge sources to the disposal facilities. Optimal design of the whole system of facilities and transport in a single program is possible, but would require a large program which would be costly to run and might be difficult to use. We have chosen to "tear" the planning problem by assuming that the facility choice and location problem could be handled separately from the transport one. What this means is that we assume that the cost of transporting sludge from the sources to the facilities could be estimated with sufficient accuracy without knowing details of the transport system, to determine facilities and sludge allocation. After this problem is solved, the transport system can be devised.

A computer program, SCHED1, has been developed, but it is described in this manual only in Appendix VIII. Although SCHED1 has not yet been put through a real test case, how this transport model could be used to complete the sludge disposal planning job is indicated. Figure 13 provides a schematic diagram showing factors entering into transport planning. The starting point for all considerations is the results obtained from ALLO2, that is, sludge sources, location of the facilities, their type and the amount of sludge to be transported between each source and facility. This provides the basis of the transport model. The transport time per link between a source and a facility or between facilities is required for all links. The transport model must have cost information in the form of cost coefficients. These come about through analysis of operating and capital costs of a trucking fleet. Sources of data and

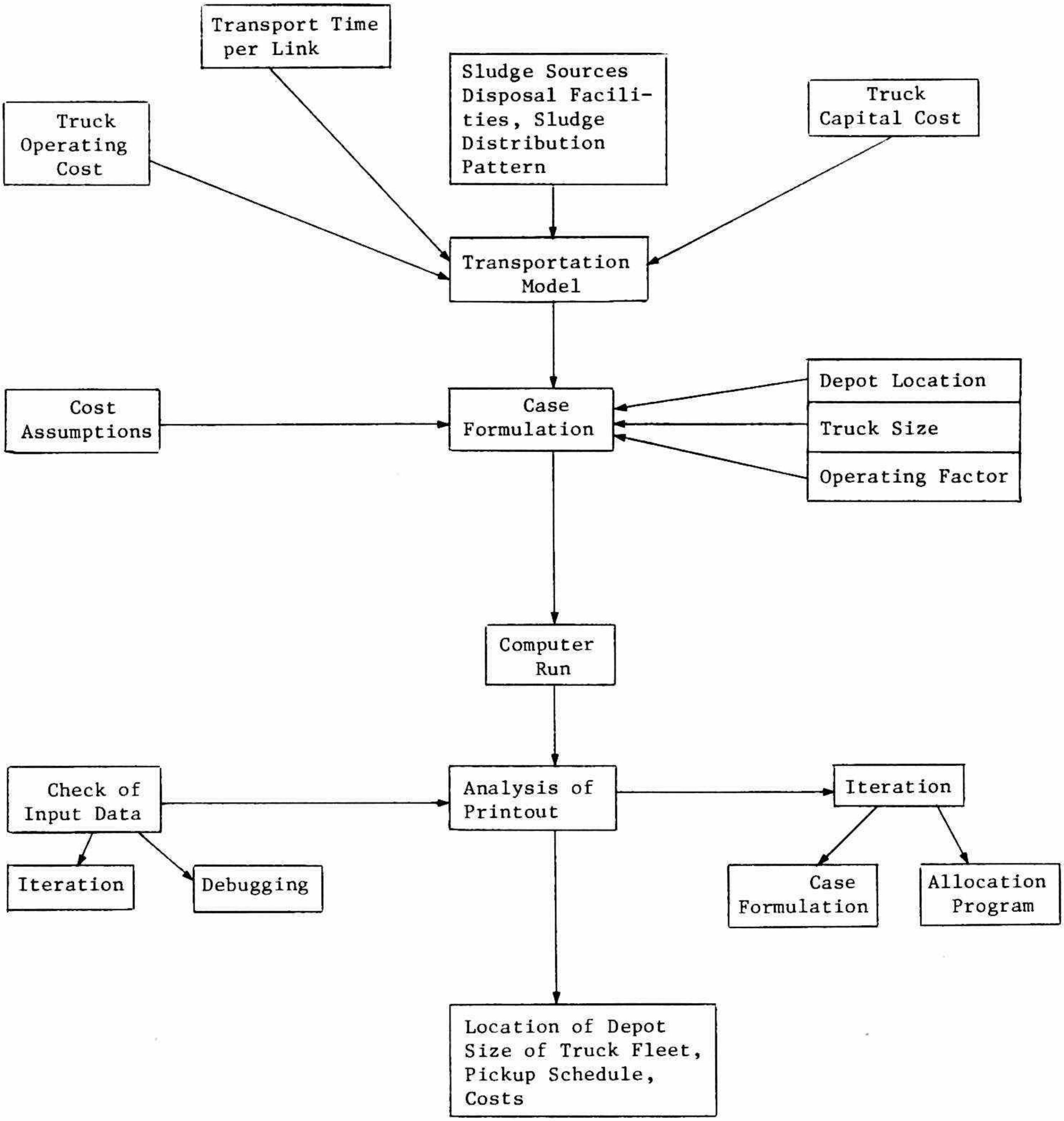


FIGURE 13. CASE FORMULATION AND USE OF THE SCHED1 PROGRAM

development of coefficients were described earlier in this chapter. The model is completed by information on alternative depot locations and size limits, along with restrictions and cost penalties (if they exist) on irregular pickup or delivery at sludge sources and facilities.

The depot is where the trucks stand when they are not in haulage service. The depot provides maintenance, refueling and facilities for the working staff of each truck. Truck size is important because it controls the number of trips which must be made between source and facility. It also influences capital and operating costs. Trucks do not operate 24 hours per day, since time must be allowed for servicing, lunch breaks, truck cleaning, etc. Operating factors vary widely. Sludge haulage trucks would have factors between 0.15 and 0.25; that is, on the average, the trucks would operate between four and six hours per day.

The transport program is used in an iterative, interactive manner just as with ALL02. A group of cases are formulated and each case is examined by the computer to yield a transport system design. Case formulation involves the choice of cost coefficients, specifying alternative locations of depots, limitations if any, size of the trucks and the number of hours per day a truck provides sludge haulage service.

Each case leads to an input deck which is run and whose output is examined. The output must first be checked to see if it is reasonable. If it is not, the input data must be carefully examined. Successive runs of SCHED1 would be examined to see what other cases should be run, that is, to see what happens if the cost assumptions change or if a different sized truck is used.

It is important to take the transport study and use it to recalculate transport costs employed in ALL02. If these differ significantly from those assumed, the facility planning program ALL02, must be re-run using the updated costs. This iterative process is suggested in Figure 2 and has already been discussed.

4. BACKGROUND FOR THE COMPUTER-AIDED FACILITIES SELECTION TECHNIQUE

We now turn our attention to the main computer program discussed in the previous chapter - the facility selection program ALL02. Our objective in the following is to review the principles and concepts which underlie the ALL02 program in order to give some of the background required to understand what the program does and how it operates. Program details will be discussed in chapters which follow. Three broad topics form this chapter. They are the role of a model in a computer program, representation of costs and, finally, techniques for selecting the optimum where a great many choices are available.

Concepts are presented in the simplest possible technical language. Detail has been avoided in order to make the material as easy as possible to understand. Where techniques, a model or representation is indeed utilized in ALL02, they will be discussed more thoroughly in future chapters.

4.1 Modelling Requirements

In planning, a common objective of making a model is to study the relationship between the total system cost and the variables which are used to describe a system. Any real systems encompass a great many variables. If a study of total system cost is accepted as the problem, then only variables that make a significant contribution to this cost need to be included in the model. In addition to restricting the number of variables, two actions are often taken to simplify the problem and thereby reduce computer costs. Constraints are imposed on the variables to avoid considering solutions that would obviously cost too much; and the relationship between the total system cost and the important variables is expressed as simply as possible while still resulting in correct comparisons of cost between different solutions.

For the specific problem at hand, the total system cost is easily broken down into the sum of costs of the elements or components of the system. These elements may be viewed as components of a material flow system. This is fortunate because the continuity of material flow from a component as input to its output yields relatively simple relationships among the important variables of the system.

There are two kinds of components in a material flow system: components for transporting material, and components for the treatment of material. The transport components should be viewed as two-ended links which join the treatment components to one another. Material, in this case sewage sludge, flows along the links among the treatment elements. A treatment component may be a "source" which produces material, or an intermediate facility for changing the properties of the material or temporarily storing it, or it may be a "sink" which provides ultimate disposal of the material. Sources have output but no input, whereas sinks have input but no output, and intermediate facilities have both input and output. In reality, everything has both input and output, but in a model a boundary must be drawn around the system outside of which everything must be ignored.

The cost of the system being modelled is the sum of the cost of each transport link plus the cost of each treatment component. The cost of each link or component will, in general, be different: it depends on the variables describing the links or components. The description of a single transport link could include the amount of material flowing on it, the method of transport used, the transport schedule and route, and so on. However, if we included all these variables and the relationships among them and those describing other transport links, the model would be too elaborate to handle. Therefore, just the one most influential variable is used, namely the amount of material flowing, and the others are ignored. The dependency of the cost of a transport link on its flow rate is expressed with fixed parameters or coefficients that imply some assumptions about the ignored variables, such as the "distance of transport is ten miles" and "the method of transport is always the optimum for the flow rate", etc. After all the flow rates have been planned, we could go into the details of transport and check on the correctness of these assumptions. If the assumptions turn out to be significantly incorrect for the planned flow rates, we could modify them appropriately and see if this changes the model enough to change our planned flow rates. You will recall that we discussed this at the end of Chapter 3. We do not expect such changes to be often required in our applications.

Similarly, the description of a treatment component could include the flow rate on each transport link connected to it, the schedule of delivery and pickup of input and output, the type of treatment and the equipment used to do it, the name of the maintenance man's union boss, and so on. Again to avoid an unmanageably elaborate model, we use the most influential variable, namely the total flow of sludge into the component. The cost coefficients that are entered in the data imply assumptions about the components, such as "for a given treatment, the equipment is always the optimum for the total input plus 30% to allow for growth", and "we must hire one shift of labour for every million gallons input", etc.

4.2 Cost Representation

In a computer model, the cost of a transport link or a treatment component is related to the description of the link (or component) by a mathematical function such as those illustrated in Figure 14. These cost functions give the cost of individual components for any possible descriptions of the components, at least within the constraints on their size. An important property of a cost function is that the cost of a component goes to zero when its flow rate or total input goes to zero, since the component then has no use in the system and is not considered a real part of it. Cost functions are typically irregular and often contain sharp jumps because equipment is sold in discrete rather than continuous sizes, labour costs are functions of whole numbers, and methods of operation may vary continuously with flow or input.

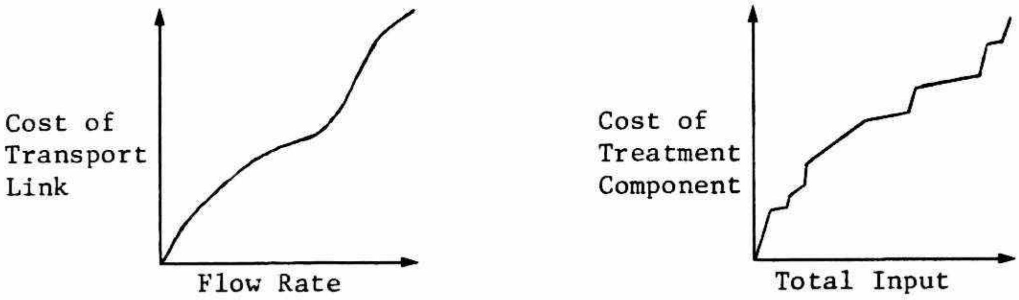


FIGURE 14. COST FUNCTIONS FOR SYSTEM COMPONENTS

Just as there are cost functions for components, so there is a cost function for the whole system. This is expressed, mathematically, simply as the sum of the cost functions for all the components. A graph cannot be drawn of the total cost relationship because it usually expresses cost as a function of not one or two, but three or more variables. This function gives the total system cost for any possible description of the whole system, at least within the constraints on its size. In an optimization study, the normal objective is to find the values of the variables, within the imposed constraints, that yield the lowest total system cost. Therefore, it is customary to call the cost function for the whole system the "objective function".

4.3 Solution Methods

4.3.1 General

The final topic of this chapter is a review of the state-of-the-art in the problem of efficiently finding the optimal solution, that is, the solution that yields the minimum value of the objective function within the imposed constraints. The most sophisticated approach found for regional waste treatment applications is reported in a paper (in English) written by a German group (Hahn et al, 1973). This paper describes a "branch and bound" method - that is, a method in which not all of the variables describing the system have had their values defined before a decision is made whether those variables, which already have values defined, are correct for the optimal solution. Thus, the method begins by defining, for a small number of variables, values which have no apparent contradiction with the optimum. Then, values are defined for some more variables ("a branch is made") until it is apparent that the values are in contradiction with the optimum; so the path of search for correct values is then retraced ("the branch is bounded and the path backtraced") until all variables with incorrect values have apparently been "undefined" again and a new branch can be made.

This method has much intuitive appeal and it can handle component cost functions of any shape; but to be efficient it requires extensive use of the local peculiarities of the application and it requires a very long computer program. The paper referred to reports a 4000-line Fortran program (compared to our own 1700-line Fortran program, ALLO2). Furthermore, it appears that the 4000-line program reported on can only consider treatment components which have either inputs or outputs, but not both.

All other approaches approximate the component cost functions with some kind of mathematically regular curves and use the special mathematical properties of these curves to find the optimal solution. These approaches are commonly labelled "mathematical programming". The continuity properties of the material flow system are very important in these approaches. This means, for instance, that the total flow rate on transport links leaving a treatment component must be equal to its total production. Assumptions are made regarding the component's efficiency in order to express its production as a simple function of its total input, which in turn must equal the total flow rate on transport links entering the component. The optimal solution can be obtained by a computer program which is not excessively long, but which may have to run through a very large number of iterations, depending on the kind of curves used to approximate the model, and on the number of variables in the model.

Three kinds of curves most commonly used to approximate component cost functions are illustrated in Figure 15. Diagram (a) illustrates a fractional power or root function. This curve does a good job of representing economies of scale, but it tends to move to the right too fast at the beginning, implying an unrealistic economy for small components. Another difficulty is the combination of its nonlinear and its "concave-down" characteristics: nonlinearity, in general, requires more computation than linearity and a concave-down component cost curve induces some "decoy" solutions which lure the computation procedure away from the desired optimal solution. The desired optimal solution is called the "global"

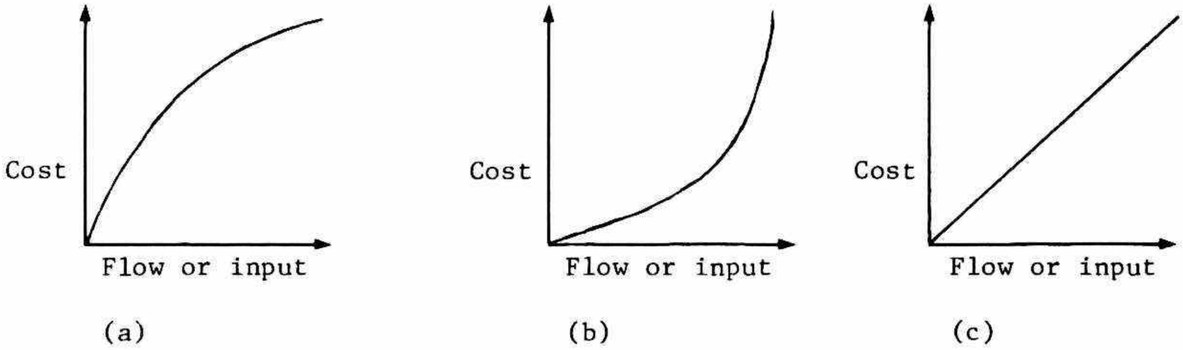


FIGURE 15. COMMON SHAPES ASSUMED FOR COST FUNCTIONS IN MATHEMATICAL PROGRAMMING

optimum, meaning that no other set of values for the system variables, anywhere within the imposed constraints, yields a lower value for the objective function. On the other hand, the type of "decoy" solution referred to above is called a "local" optimum. The local optimum exists because no other set of values for the system variables, within some boundary surrounding the solution at an arbitrary small distance, yields a lower value for the objective function.

Diagrams (b) and (c) represent quadratic and linear functions. These curves give no problems with local optima, but they are often poor approximations to the actual cost function. Nevertheless, they are often used, since they greatly facilitate computation - especially the linear curve.

4.3.2 Linear programming

Mathematical programming may be called, more explicitly, nonlinear, quadratic, or linear programming depending on the shape of the cost function curves used.

Special cases of linear programming have received much attention and have had methods of computation developed which are very fast and easy, but quite mystical for the nonmathematician. One case which is often encountered and occurs frequently in ALLO2 is called the "transportation" problem. The problem arises when an optimal solution is to be found for a material flow system in which there are transport links only from sources to sinks; the only costs are those of the transport links; these have linear cost functions; and the only constraints are that the total flow rate on links leaving a source must equal the given output of that source and the total flow rate on links entering a sink must be less than the given size limit of that sink. The method for the transportation problem can also be used when treatment components with both inputs and outputs are included, if these are reinterpreted as special sink/source combinations. In this case, the problem is called a "transshipment" problem. ALLO2 does not use the transshipment problem. Due to the special characteristics of the sludge disposal planning application, each transshipment problem can always be reduced to two transportation problems.

At this point, the "dual" of a linear programming problem must be mentioned, since our method of solving the transportation problem involves solving its dual. Referring to any part of a given linear programming problem as "primal", we describe as "dual" the parts of the linear programming problem which are related to the primal problem as follows:

- the dual variables are the coefficients in the primal constraints;
- the coefficients in the dual constraints are the primal variables;
- the dual objective function parameters are the limits of the primal constraints; and,
- the limits of the dual constraints are the primal objective function parameters.

The optimal solutions of the two problems are easily related, and although the objective function is maximized in the one problem whereas it is minimized in the other, the optimal solutions yield identical objective function values in each problem. During some stages when solving certain types of linear programming problems, such as transportation problems, it is easier to work on the dual problem rather than the primal. Such a method, which alternates between the primal and dual problems, is appropriately called a "primal-dual" method.

4.3.3 Fixed-charge linear models

In order to overcome a great deal of the lack of precision which the straight line in Figure 15(c) causes in the model, especially for treatment components, two devices can be advantageously used without getting into the complications of piecewise-linear curves. A "fixed charge" can be added, and a constraint can be put on the horizontal axis: this then results in a curve as shown in Figure 16. The fixed charge is not added when the total input is zero, only when it is over zero. The constraint has the effect of making the cost go to infinity for any total input at or over the limit value of the constraint.

Models which contain such "fixed-charge cost functions" can be handled by a form of linear programming if each fixed-charge cost function is viewed as the sum of a linear function and a step function. The step

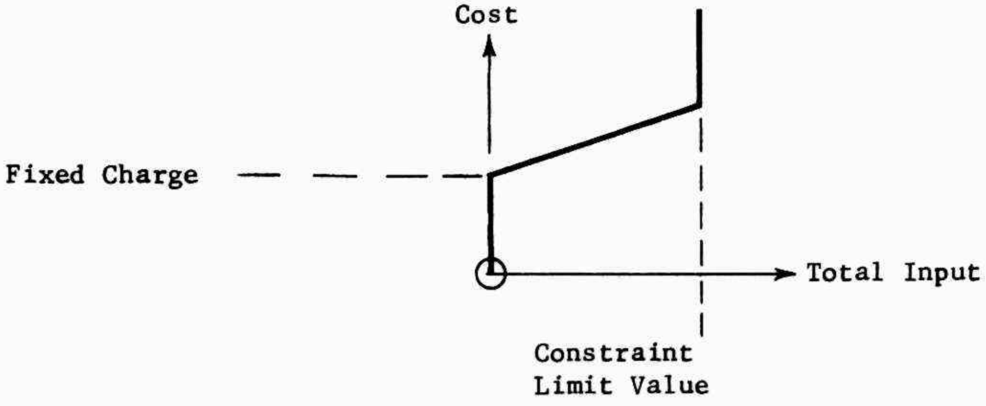


FIGURE 16. LINEAR COST FUNCTION WITH FIXED CHARGE AND CONSTRAINT

function is made a linear function of an artificial variable as shown in Figure 17. The artificial variable is defined such that it takes the value zero if the total input to the component is zero, and one otherwise. Constraints that impose an integer value on a variable are difficult to handle mathematically. A special approach called "integer linear programming" is required, or rather "mixed integer linear programming" since not all the variables in the model are restricted to integer values. To date, these approaches are still in the developmental stage and cannot be counted on to produce a solution efficiently, although they can be very successful with a large amount of research on a specific type of problem.

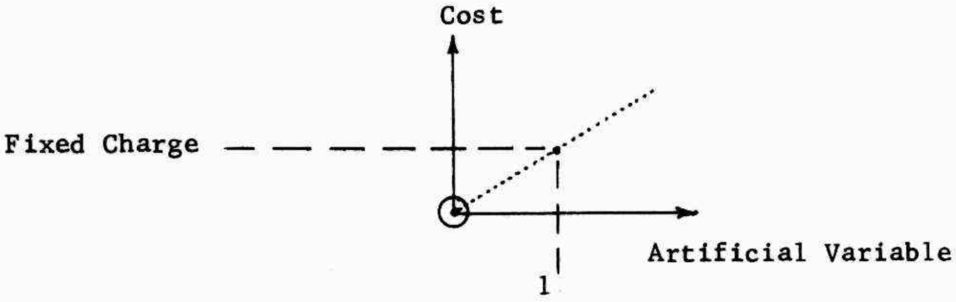


FIGURE 17. LINEARIZATION OF THE STEP FUNCTION

A more reliable approach to models containing fixed-charge cost functions is to find the optimal solution repeatedly, each time selecting a different set of components, which have fixed charges, as being free to have total inputs over zero. Each time, the contribution of fixed charges to the objective function is counted only from those components thus permitted in the system; the fixed charge terms of the cost functions are then removed and the problem is solved with normal linear programming. The combination of components that yields the lowest total system cost, including both the fixed charges and the contribution obtained by linear programming, yields the optimal solution (the global optimum, as opposed to the local optima obtained with each given combination of components). The only disadvantage of this approach is that the total number of possible combinations of components may be very large, so that the search for the best one may require a large number of applications of linear programming. In the next chapter, special techniques are discussed which minimize this disadvantage in our particular application.

5. THE ALLO2 MODEL

5.1 Introduction

The purpose of this chapter is to show you how a sludge disposal system is reduced to a model which can be represented by numbers and relationships. The sludge disposal is made more complicated by the necessity of considering two seasons. Much of the chapter is devoted, therefore, to describing the two-season model we have developed. Structure and operation of the ALLO2 facility selection program are discussed in the final third of the chapter. The orientation of this chapter is toward those charged with carrying out sludge disposal studies, that is, the users of the ALLO2 program.

5.2 Model Structure

The material flow system described in the previous chapter can be defined in a more specific way to model regional sludge disposal. Treatment components can be classified into different types by the characteristics they exhibit. This allows us to ignore transport links between certain types of treatment components. Incorporating specific information into the model in this way makes it easier to find the optimal solution to the planning problem. This information does not restrict the model and can still represent the majority of situations that may arise.

5.2.1 Classification of facilities

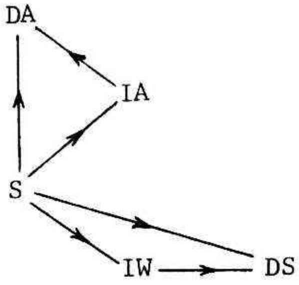
The sludge disposal system model should be viewed as a two-stage material flow system. Sources in the system are linked to intermediate facilities which, in turn, are linked to the system's sinks. The sources may also be linked directly to sinks. To provide a more descriptive term for sinks, they are referred to as "dead-end" facilities. Dead-end facilities often represent landfills or agricultural land spreading sites. However, they may also represent facilities whose outputs, though normally included in the model, may be excluded in special cases, such as drying facilities where sludge is removed by private parties.

Dead-end facilities are classified into two types: those that can be used all year (such as landfills), and those that cannot (such as land spreads). These are designated as "all-year dead-end" and "summer dead-end" facilities, respectively. All summer dead-end facilities in a model are prohibited from use during a period of the year designated as "winter". Thus the year is divided into just two parts, "winter" and "summer".

Intermediate facilities are also classified into two types: those available to receive material from sources in the winter (such as holding tanks) in order to distribute it among summer dead-end facilities in the summer; and those (as is often the case with drying facilities) which have nothing to do with summer dead-end facilities. These are designated as "winter intermediate" and "all-year intermediate" facilities, respectively.

5.2.2 Types of transport links

The types of transport links involved in the model are shown in Figure 18.



DA = all-year dead-end facilities
IA = all-year intermediate facilities
S = sources
IW = winter intermediate facilities
DS = summer dead-end facilities

FIGURE 18. TYPES OF TRANSPORT LINKS INCLUDED IN THE MODEL

In words: transport links are included from all sources to all facilities, from all all-year intermediate to all all-year dead-end facilities, and from all winter intermediate to all summer dead-end facilities. Seasonal restrictions on the transport links are imposed as follows: in summer, all links from sources or winter intermediate facilities are disallowed, and in winter, all links from sources or winter intermediate facilities to summer dead-end facilities are disallowed. The winter restriction ensures that summer dead-end facilities receive no input during the winter; the summer restriction ensures that the winter intermediate facilities can start off each winter season empty.

5.2.3 Potential facilities

The computer program ALL02 assumes the type of model, as described here, in its general form. A user must define the number of sources and the number of facilities of each type. In a typical regional problem there are 5 to 10 sources large enough to include in the model, and the planner may wish to have 10 to 25 facilities considered by the computer. Some of these facilities may already exist, but probably most of them are only postulated as being feasible at given locations. All the facilities to be considered by the computer, whether existing or postulated, may be called the "potential facilities" i.e., those which are potentially in the optimal solution. It is important that the planner have a location and a type of treatment in mind for each of the potential facilities, so that cost functions and the connecting transport links can be set up. Models which have facility location or type of treatment as a variable, rather than as a fixed parameter, cannot be made practical. Location and type of treatment are not variables in the ALL02 program. However, in this model, several facilities may effectively represent the same type of treatment component, e.g. landfill, at different locations. By the same token, several facilities may represent different possible types of treatment at the same location. When the computer finds the least cost set of sludge flows for the transport links, i.e., the optimal solution, those facilities with total input over zero are viewed as the optimal combination of facilities that ought to exist. (Thus, optimal solution is synonomous with optimal combination of facilities.) The computer, by choosing among facilities in this way, may sometimes effectively be choosing among locations for the same type of treatment component, or among types of treatment for the same location.

5.3 Cost Functions

5.3.1 Component cost functions

The model assumes simple linear cost functions for the transport links and fixed-charge linear cost functions for the intermediate and dead-end facilities. The program must be given coefficients to describe the cost functions in terms of the slopes of the curves, the magnitudes of the fixed charges, and the limit values of the constraints imposed on the total input to the facilities. All-year dead-end facilities are exceptions to the rule that a constraint on total input makes a facility cost function jump straight up, since these particular dead-end facilities are conceived as usually being landfills receiving dried sludge from intermediate facilities. This also means that they do not handle the type of sludge which is more difficult to apply in a landfill, namely, liquid sludge. So, for an all-year dead-end facility, although the cost function is total input (regardless of its origin) on the horizontal axis, the point at which the cost function jumps straight up is variable. It is the point at which the subtotal of input directly from sources reaches the limit value of the constraint.

5.3.2 System cost function

Figure 19 shows the model broken down into summer and winter systems. Types of transport links possible in winter are shown in solid lines, and those possible in summer are shown in dotted lines. The symbols S, IA and DA represent the complete set of sources, all-year intermediate facilities, and all-year dead-end facilities, respectively; all of these components appear twice, once in winter and once in summer. The symbols IW and DS represent winter intermediate facilities and summer dead-end facilities, respectively; these elements appear just once.

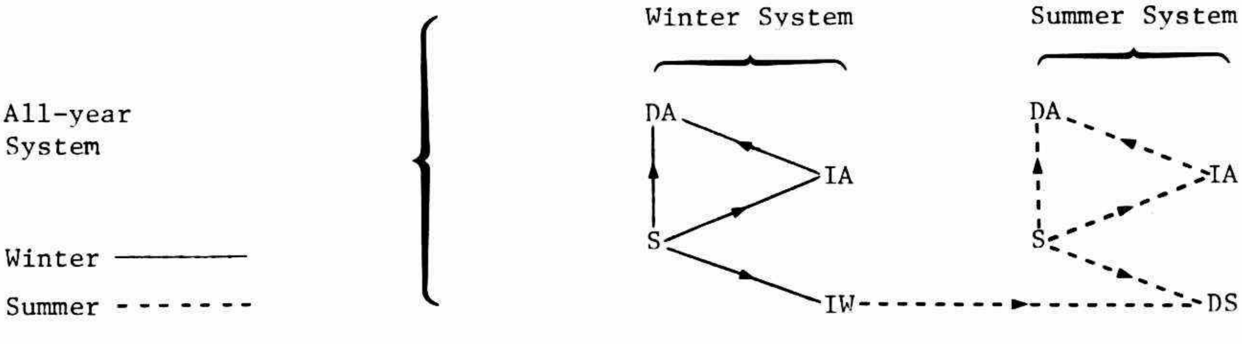


FIGURE 19. TYPES OF TRANSPORT LINKS IN THE MODEL, BROKEN DOWN INTO SEASONS

For any set of values for the variables representing flows in the transport links, the model assumes the total system cost can be calculated as follows, as long as no constraints (to be described later) are violated. Denoting the total flow in the link from point i to facility m by X_{im} in the winter and Z_{im} in the summer, and the slope of the linear transport link cost functions by C_{im}; then the total cost of transport links is:

$$\sum_{\substack{m=\\ \text{all DA}}} \sum_{\substack{i=\\ \text{all S}\\ \text{\& all IA}}} \left(X_{im} + Z_{im}\right) C_{im} + \sum_{\substack{m=\\ \text{all IA}}} \sum_{\substack{i=\\ \text{all S}}} \left(X_{im} + Z_{im}\right) C_{im}$$

$$+ \sum_{\substack{m=\\ \text{all IW}}} \sum_{\substack{i=\\ \text{all S}}} X_{im} C_{im} + \sum_{\substack{m=\\ \text{all DS}}} \sum_{\substack{i=\\ \text{all S}\\ \text{\& all IW}}} Z_{im} C_{im} . \quad (1)$$

Denoting the slope of the cost function of a facility m by B_m, the contribution to total system cost from the slopes of facility cost functions is:

$$\sum_{\substack{m=\\ \text{all DA}}} B_m \sum_{\substack{i=\\ \text{all S}\\ \text{\& all IA}}} \left(X_{im} + Z_{im}\right) + \sum_{\substack{m=\\ \text{all IA}}} B_m \sum_{\substack{i=\\ \text{all S}}} \left(X_{im} + Z_{im}\right)$$

$$+ \sum_{\substack{m=\\ \text{all IW}}} B_m \sum_{\substack{i=\\ \text{all S}}} X_{im} + \sum_{\substack{m=\\ \text{all DS}}} B_m \sum_{\substack{i=\\ \text{all S}\\ \text{\& all IW}}} Z_{im} . \quad (2)$$

To use this expression for the cost contribution, the cost functions for all facilities must be expressed in terms of the annual sludge input to the facility. The above two contributions (expressions (1) and (2)), may be combined into the expression:

$$\sum_{\substack{m=\\ \text{all DA}}} \; \sum_{\substack{i=\\ \text{all S}\\ \text{\& all IA}}} \left(X_{im} + Z_{im}\right)\left(B_m + C_{im}\right) + \sum_{\substack{m=\\ \text{all IA}}} \; \sum_{\substack{i=\\ \text{all S}}} \left(X_{im} + Z_{im}\right)\left(B_m + C_{im}\right)$$

$$+ \sum_{\substack{m=\\ \text{all IW}}} \; \sum_{\substack{i=\\ \text{all S}}} X_{im}\left(B_m + C_{im}\right) + \sum_{\substack{m=\\ \text{all DS}}} \; \sum_{\substack{i=\\ \text{all S}\\ \text{\& all IW}}} Z_{im}\left(B_m + C_{im}\right) . \qquad (3)$$

This may be called the "total system variable cost". The first three sums in expression (3) will be referred to as the contributions from "winter and all-year sludge distribution", and the fourth or last sum as the contribution from "summer sludge distribution". The quantity $(B_m + C_{im})$ may be referred to as the unit variable cost, or distribution cost, for a particular transport link.

To express the contribution of facility fixed charges to the total system cost, the notation $H[x]$ will be used to denote 0 if $x = 0$, and 1 if x is greater than 0. So, denoting the fixed charge in the cost function of a facility m by A_m, the total fixed cost is:

$$\sum_{\substack{m=\\ \text{all DA}}} A_m \, H\left[\sum_{\substack{i=\\ \text{all S}\\ \text{\& all IA}}} \left(X_{im} + Z_{im}\right)\right] + \sum_{\substack{m=\\ \text{all IA}}} A_m \, H\left[\sum_{\substack{i=\\ \text{all S}}} \left(X_{im} + Z_{im}\right)\right]$$

$$+ \sum_{\substack{m=\\ \text{all IW}}} A_m \, H\left[\sum_{\substack{i=\\ \text{all S}}} X_{im}\right] + \sum_{\substack{m=\\ \text{all DS}}} A_m \, H\left[\sum_{\substack{i=\\ \text{all S}\\ \text{\& all IW}}} Z_{im}\right] . \qquad (4)$$

The total system cost is just the sum of this expression plus expression (3), i.e., the total fixed cost plus the total variable cost. The combined expression is the objective function.

5.4 Constraints

The main constraint imposed on the variables (i.e., on the X's and Z's) are those required to make each facility cost function jump straight up at some point, thus putting an upper limit on the size of the facility: denoting this limit for any facility m by L_m,

if m is an IA or DA,
$$\sum_{\substack{i= \\ \text{all } S}} \left(X_{im} + Z_{im}\right) \leqslant L_m \qquad (5)$$

if m is an IW,
$$\sum_{\substack{i= \\ \text{all } S}} X_{im} \leqslant L_m \qquad (6)$$

and if m is a DS,
$$\sum_{\substack{i= \\ \text{all } S \\ \& \text{ all IW}}} Z_{im} \leqslant L_m \qquad (7)$$

On the left side of expressions (5), (6) and (7) is the total input to facility m, with the exception that in expression (5), if the facility is an all-year dead-end facility, then the sum does not include input from intermediate facilities, but only from all sources. On the right side of these three expressions is the limit, for the quantity on the left side, beyond which the computer program does not let the left side vary when it is looking for the least cost values for sludge flows on the transport links. This has the effect of having the facility cost functions jump to infinity at these limits on input (or size). The relationships between the output and input of intermediate facilities are also viewed as constraints. Denoting by V_m the given "volume reduction factor" or ratio of volume out over volume in, for any facility m,

$$\text{if } m \text{ is an IA,} \quad \sum_{\substack{j= \\ \text{all DA}}} Z_{mj} = V_m \sum_{\substack{i= \\ \text{all S}}} X_{im} \tag{8}$$

$$\text{if } m \text{ is an IW,} \quad \sum_{\substack{j= \\ \text{all DS}}} Z_{mj} = V_m \sum_{\substack{i= \\ \text{all S}}} X_{im} \tag{9}$$

Note that the volume reduction factor is associated with a facility; it is assumed to be the same for that facility regardless of the source of the sludge.

Of course, the model also imposes constraints which ensure that the given output of each source is entirely disposed of: denoting by Q_i the output of any source i,

$$\sum_{\substack{m= \\ \text{All IA} \\ \text{\& all DA}}} \left(X_{im} + Z_{im} \right) + \sum_{\substack{m= \\ \text{all IW}}} X_{im} + \sum_{\substack{m= \\ \text{all DS}}} Z_{im} = Q_i \tag{10}$$

5.5 General Optimization Strategy

As explained in Chapter 4, the least cost combination of facilities is found by repeatedly finding least cost values for sludge flows in the transport links with different combinations of potential facilities permitted to have input greater than zero. Our program effectively does this by repeatedly rebuilding the model, including a different combination of facilities each time. With each reconstruction it finds the values of the X's and Z's that yield the lowest total variable cost (expression (3)). The sum of this cost plus the total fixed charges for the given combination of facilities yields a total system cost used to compare it with other combinations of facilities. All possible combinations of facilities are compared in this way, finally producing the global optimum and several near-optimal combinations of facilities.

The total fixed charges may, of course, overestimate expression (4), since some facilities in the combination may have zero input in the optimal set of sludge flows. However, the combinations of facilities are enumerated in such an order that this never causes any difficulty.

The program optimizes the sludge distribution for a given combination of facilities by the following process. First, the winter distribution is optimized (flows on transport links of the type indicated by solid lines in Figure 19). This builds up a certain inventory in winter intermediate facilities (if there are any in the combination). Then the summer distribution is optimized (flows on transport links of the type indicated by dotted lines in Figure 19). In the summer, the entire inventory of each intermediate facility, as modified by its volume reduction factor, is sent to summer dead-end facilities.

Optimization of summer distribution is facilitated by the following assumption. It is to be expected that transportation considerations would give any all-year facility (either intermediate or dead-end) a constant input rate all year. Therefore, the program assumes that the summer flows (Z's) on transport links connected to all-year facilities must give the same rate in summer as the winter flows (X's) give on the same links in the winter. Let W be the fraction of the year that is winter. For the rate in summer, $Z/(1-W)$, to equal the rate in winter, X/W, then Z must be just $X\ (1-W)/W$ for each all-year link.

Due to this assumption, it follows that a source that sends some amount of sludge to winter intermediate facilities in winter must send sludge at the same rate to summer dead-end facilities in summer. So the procedure generates the constraints shown in expression (11) for all sources i. All flow patterns considered by the program follow these constraints.

The only problem left in the summer distribution is then to determine the optimal flows on the transport links from sources and winter

$$\sum_{\substack{m= \\ \text{all DS}}} Z_{im} = \frac{1 - W}{W} \sum_{\substack{m= \\ \text{all IW}}} X_{im} \tag{11}$$

intermediate facilities to summer dead-end facilities. Therefore, the program builds a model of this summer subsystem, using the above expression to calculate source outputs and the inventory accumulated in winter to calculate the outputs from winter intermediate facilities. If any of these outputs are found to be zero, the source or facility is left out of the summer subsystem model. Since this model is our main interest when we are concerned with the summer distribution, we shall often call it "the summer system" even though it excludes the all-year subsystem that is also operating in the summer. The all-year subsystem is constant all year and directly determined by the winter optimization.

In the process of optimizing the distribution for a particular combination of facilities, we associate the all-year system very closely with the winter system, and hardly at all with the summer system. The whole system becomes divided conceptually into the two parts "winter and all-year system" and "summer system (excluding all-year system)".

5.6 Details of the Technique

Now that the optimization process has been described once, we shall go over it again and add a few details.

5.6.1 The weighting factor

In order to optimize the transport link flows for the winter sludge distribution for a particular combination of facilities, the program takes as its objective function that part of the total system variable cost (expression (3)) that pertains to the winter system (expression (12)). There is no consideration, in this expression, for the cost of the summer system. However, the minimum cost of the summer system is strongly dependent on the winter optimization. Not only is the all-year system (which is operating in the summer) directly determined

$$\sum_{\substack{m=\\ \text{all DA}}} \sum_{\substack{i=\\ \text{all S}\\ \text{\& all IA}}} X_{im}\left(B_m + C_{im}\right) + \sum_{\substack{m=\\ \text{all IA}}} \sum_{\substack{i=\\ \text{all S}}} X_{im}\left(B_m + C_{im}\right)$$

$$+ \sum_{\substack{m=\\ \text{all IW}}} \sum_{\substack{i=\\ \text{all S}}} X_{im}\left(B_m + C_{im}\right) \tag{12}$$

by the winter optimization, but also the summer system (excluding the all-year system) has to satisfy the demands put on it by the inventory in winter intermediate facilities and the sources that created that inventory.

It is conceivable that the least cost winter and all-year system could lead to a high cost summer system, whereas another choice of the former could give a low cost summer system and a lower total system cost. In order to achieve the correct balance between the cost of the winter system and the cost of the summer system, the program actually uses a bias on the first two of the three sums in the expression (12). That is, in the objective function actually used to optimize the winter system, these first two sums are multiplied by $2^{(F/2)}$, where F is a weighting factor given to the program as data. If F = 0, there is no change (no bias). If F is *greater* than 0, the modified objective function biases optimization in *favour* of using winter intermediate rather than all-year dead-end or intermediate facilities; this tends to put *more* demand on the summer system. On the other hand, if F is *less* than 0, the modified objective function biases optimization *against* using winter intermediate rather than all-year dead-end or intermediate facilities; this tends to put *less* demand on the summer system.

Later, in Chapter 6, the procedure for making trials to estimate the best value for F will be described. In our experience, no more than three values need to be tried to find one that yields an approximate global optimum within 1% of the correct solution. Such accuracy is more than adequate, especially in view of the uncertainty that always accompanies the data given to the program to describe the cost functions. Our approximate method yields valuable savings in computing time: the alternative is to use a program that would optimize the winter and summer systems simultaneously, which would at least double the computing costs.

5.6.2 Cost calculations

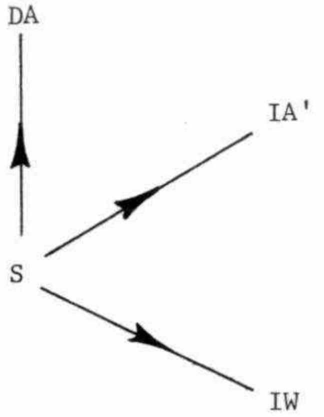
When the winter sludge distribution has been optimized, the program immediately calculates the contribution to total variable cost from not only the winter system, but the winter and all-year systems: this is expression (12), using the optimized X's, with the first two sums divided by W, since for the all-year system the summer flows are $Z = \left(\frac{1 - W}{W}\right) X$ and the total annual flows are $X + Z = \left(\frac{W + 1 - W}{W}\right) X = X/W$, where W is the fraction of the year that is "winter". If the program is asked to print out the solution, it gives at this point the total annual flows (winter plus summer) for the all-year system, the winter flows for the winter system (excluding the all-year system), and the contribution to total variable cost from both the winter and the all-year distribution.

Then the model for the summer subsystem is set up, the summer distribution optimized, and if printing-out of the solution is called for, the optimal Z's are printed out along with the contribution to total variable cost from this optimized summer distribution.

5.6.3 The use of linear programming

Linear programming is used extensively in ALLO2. It is not necessary to know the details of its use unless modification of the program is intended. In that case, you should refer to the detailed program description in Appendix V. Here, we shall just indicate where linear programming is used in the optimization process.

To optimize the winter distribution for a particular combination of facilities, the program first assigns, to each all-year intermediate facility i, the all-year dead-end facility, m, that gives the lowest value of $\left(B_m + C_{im}\right)$. The value of B_i, the variable cost coefficient of the intermediate facility, is then raised by $\left(B_m + C_{im}\right) V_i$ where, V_i is the volume reduction factor of intermediate facility i. That is, each all-year intermediate facility i has the variable cost of ultimate disposal to the cheapest dead-end facility incorporated into its own variable cost. Now the model of the winter system has been reduced to a one-stage system as shown in Figure 20.



IA' = all-year intermediate facilities with cost of ultimate disposal incorporated into variable cost

FIGURE 20. WINTER SYSTEM AFTER ASSIGNMENT OF ALL-YEAR DEAD-END FACILITIES TO ALL-YEAR INTERMEDIATE FACILITIES

There are only sources (S) linked directly to sinks (DA, IA', and IW). The prime on IA designates that facilities in this set have had their variable cost augmented by the cost of ultimate disposal to all-year dead-end facilities. The costs of this system are the unit variable costs $(B_j + C_{ij})$ for each link* from source i to sink j where B_j is suitably augmented for members of IA'; and the constraints on the system are that each source must have its total output (annual output multiplied by W, since this is just for winter) disposed of, and that no sink can have total input larger than its limit (annual limit multiplied by W unless it is a winter intermediate facility). The optimization of this system is the "transportation problem", a simple case of linear programming, as explained in the preceding chapter.

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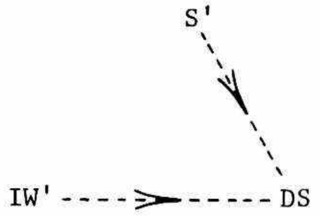
* For links to DA or IA' facilities, the variable cost is multiplied by $2^{(F/2)}$ for biasing.

To optimize the summer distribution, the model of the subsystem, as shown in Figure 21, is interpreted immediately as a transportation problem.



S' = sources which sent sludge to IW facilities in winter.

IW' = winter intermediate facilities that received sludge in winter.

FIGURE 21. SUMMER SYSTEM (EXCLUDING ALL-YEAR SYSTEM) WITH SELECTED SOURCES AND WINTER INTERMEDIATE FACILITIES.

There are just sources (S' and IW') linked to sinks (summer dead-end facilities). The costs of this system are the unit variable costs $(B_j + C_{ij})$ for each link from point i to point j, and the constraints on it are that each member of S' must have its total output (as obtained by equation (11)) disposed of, and that each member of IW' must have its total output (as obtained by equation (9)) disposed of, and that no member of DS can have total input larger than its limit.

Thus, there are two transportation problems to solve for each particular combination of facilities, one for the winter and one for summer. This can be done very quickly by the primal-dual method, especially in this program, which maintains lists of pointers to monitor the elements of the sparse matrices involved.

5.7 General Operation of the ALLO2 Program

In the preceding sections of this chapter, the model on which the ALLO2 program is based has been described. Some mention of the program has been made in order to indicate how it and the results it gives are affected by the model's assumptions. To understand how the program is best applied in planning, further discussion is necessary.

In the remainder of the chapter, we shall look at the general operation of ALL02.

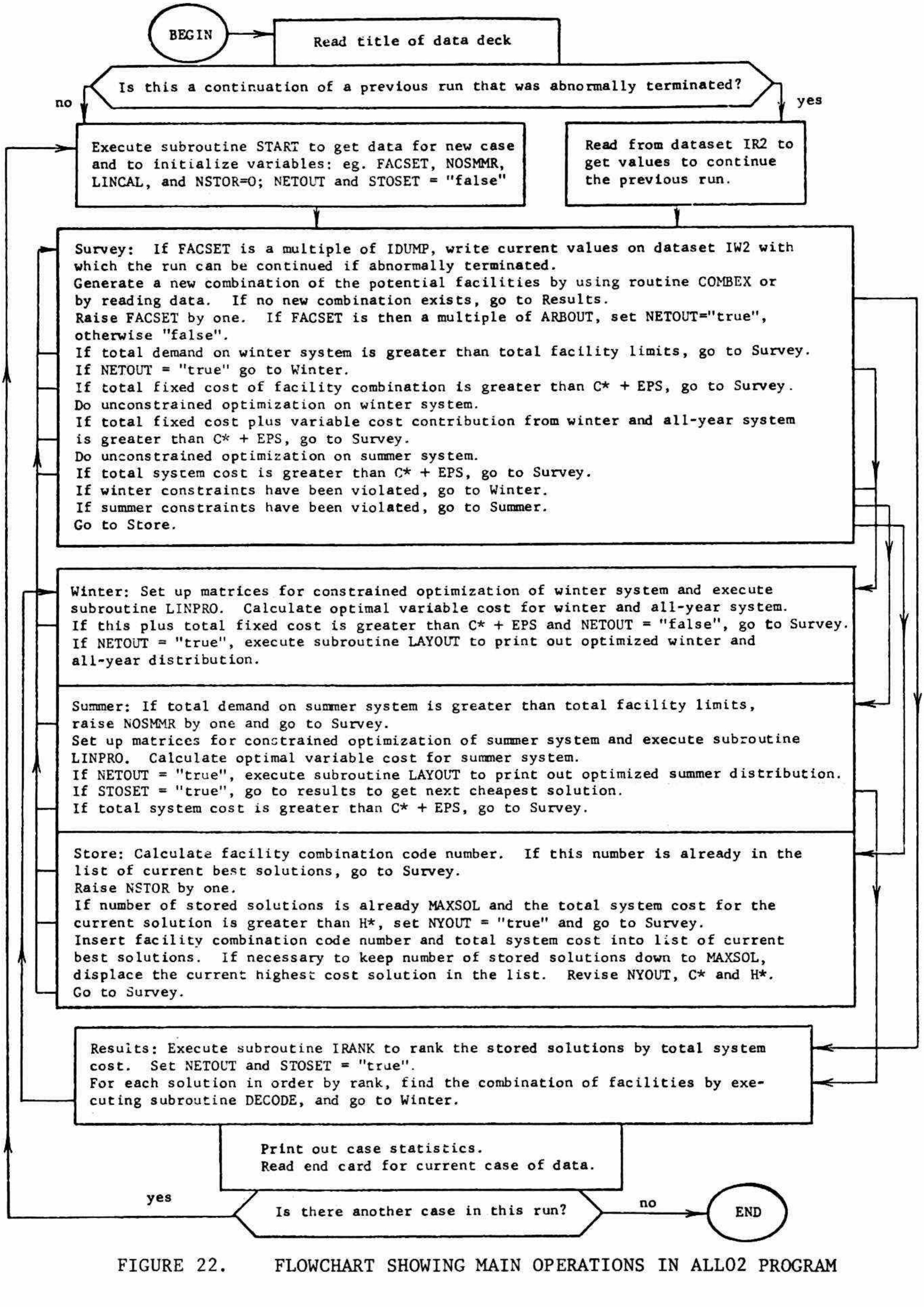
5.7.1 Components of the program

Figure 22 shows a flow chart of the ALL02 program. It should be read from top to bottom, following the arrows to skip up or down when stated conditions are met. This is what may be called the "main routine" of the program. It contains a large number of small routines; it also refers to several routines which are external to it, called "subroutines". In addition to the main routine and the subroutines, the ALL02 program contains some special "functions". It also contains a "block data" subprogram that initiates certain quantities whenever the program is run.

This flowchart will now be discussed with elaboration and comments to provide an understanding of how the ALL02 program works.

At the top of the chart the program divides into two parrallel paths. The path taken depends on whether the title card of the data deck has indicated that the run is to be a continuation of a previous run. If not, as normally happens, the data deck is read by a subroutine START to get a "case" of data. This point in the program may also be reached after a "case" is finished, in order to start a new "case". A "case" is a set of information such as source outputs, facility cost coefficients and size limits, and transport link cost coefficients. Before reading the first case in a run, subroutine START reads the data deck to obtain information which is the same for all cases in the run, such as the number of sources and the number of facilities of each kind. The global optimum is found for each case in a run. The primary purpose of running more than one case at once is to compare results for different points in time; as time goes on, production at sources usually rise and certain costs may increase. This is done slightly more efficiently in one run than in separate runs, since some of the information stays the same. Different cases in a run may also be used to determine the effect of changing cost functions that contain some uncertainty.

Subroutine START also initiates all variables which must have this done for each case. The variables mentioned in the flowchart will be explained as we go along. Of particular interest is FACSET, which



Read title of data deck

Is this a continuation of a previous run that was abnormally terminated?

Execute subroutine START to get data for new case and to initialize variables: eg. FACSET, NOSMMR, LINCAL, and NSTOR=0; NETOUT and STOSET = "false"

Read from dataset IR2 to get values to continue the previous run.

Survey: If FACSET is a multiple of IDUMP, write current values on dataset IW2 with which the run can be continued if abnormally terminated.
Generate a new combination of the potential facilities by using routine COMBEX or by reading data. If no new combination exists, go to Results.
Raise FACSET by one. If FACSET is then a multiple of ARBOUT, set NETOUT="true", otherwise "false".
If total demand on winter system is greater than total facility limits, go to Survey.
If NETOUT = "true" go to Winter.
If total fixed cost of facility combination is greater than C* + EPS, go to Survey.
Do unconstrained optimization on winter system.
If total fixed cost plus variable cost contribution from winter and all-year system is greater than C* + EPS, go to Survey.
Do unconstrained optimization on summer system.
If total system cost is greater than C* + EPS, go to Survey.
If winter constraints have been violated, go to Winter.
If summer constraints have been violated, go to Summer.
Go to Store.

Winter: Set up matrices for constrained optimization of winter system and execute subroutine LINPRO. Calculate optimal variable cost for winter and all-year system.
If this plus total fixed cost is greater than C* + EPS and NETOUT = "false", go to Survey.
If NETOUT = "true", execute subroutine LAYOUT to print out optimized winter and all-year distribution.

Summer: If total demand on summer system is greater than total facility limits, raise NOSMMR by one and go to Survey.
Set up matrices for constrained optimization of summer system and execute subroutine LINPRO. Calculate optimal variable cost for summer system.
If NETOUT = "true", execute subroutine LAYOUT to print out optimized summer distribution.
If STOSET = "true", go to results to get next cheapest solution.
If total system cost is greater than C* + EPS, go to Survey.

Store: Calculate facility combination code number. If this number is already in the list of current best solutions, go to Survey.
Raise NSTOR by one.
If number of stored solutions is already MAXSOL and the total system cost for the current solution is greater than H*, set NYOUT = "true" and go to Survey.
Insert facility combination code number and total system cost into list of current best solutions. If necessary to keep number of stored solutions down to MAXSOL, displace the current highest cost solution in the list. Revise NYOUT, C* and H*.
Go to Survey.

Results: Execute subroutine IRANK to rank the stored solutions by total system cost. Set NETOUT and STOSET = "true".
For each solution in order by rank, find the combination of facilities by executing subroutine DECODE, and go to Winter.

Print out case statistics.
Read end card for current case of data.

Is there another case in this run?

FIGURE 22. FLOWCHART SHOWING MAIN OPERATIONS IN ALLO2 PROGRAM

is a running count of the number of facility combinations that have been generated for evaluation in a case.

5.7.2 Normal survey and storage of solutions

Now let us examine the structure of the program involving the blocks labelled "Survey", "Winter", "Summer", "Store", and "Results". With each combination of facilities generated in Survey, an attempt is made to optimize the Winter and Summer sludge distribution. During this optimization, the facility combination is screened to see if it compares well enough with the facility combinations stored in the current list of best solutions, to provide an opportunity for it to be stored in this list. As the optimization proceeds, the variable cost in the objective function increases. Since the total system cost is certainly higher than the total fixed charges plus the variable cost at any point except the optimum one, as soon as this exceeds a given criterion, the solution is abandoned and Survey begins again with a new facility combination. The criterion is C* + EPS, where C* is the cheapest total system cost among the solutions in the list of the current best, and EPS is a quantity read in as data at the beginning of the run. EPS is the margin, above the optimal solution, beyond which the user is not interested in any near-optimal solutions.

As well as C*, the list of current best solutions has two other important attributes: H*, the highest total system cost among the solutions in the list, and MAXSOL, the maximum number of solutions the list may contain. The list starts out empty at the beginning of a case and fills up as different facility combinations are evaluated; during this time C* and H* will decrease but MAXSOL, which is read in as data at the beginning of the run, stays the same.

If a facility combination passes through all screening as the sludge distribution to the facilities is optimized, then the block Store calculates a code number that uniquely identifies the potential facilities in the combination which have total input over zero. The list of current best solutions contains only such code numbers and the corresponding total system costs. If the list already contains a code number equal to that of the combination of facilities now under consideration, the combination is abandoned and Survey starts again. Otherwise an attempt is made to store the facility combination in the list. NSTOR is a running count of the number of such attempts in the case. The word "attempts" is used because the combination cannot be stored in the list if the list is already full and H* is less than the total system cost of the combination under consideration. The program contains an indicator, NYOUT, which has the value "true" whenever H* is lower than C* + EPS and a facility combination falling between H* and C* + EPS has been rejected from the list of current best solutions. If an attempt to store a facility combination (that is, its code number and total system cost) is not thwarted in this way, it is necessary to discard the member of the list with cost H* in order to make room for the new member, if the list has already reached full size. When this process is finished Survey begins again with a new combination of facilities.

When there are no more facility combinations, the block "Results" takes over to print out the final list of best solutions. Much time and space has been saved by storing each solution in terms of just a code number and its total system cost, but now some time must be spent on decoding each number, using subroutine DECODE, and optimizing the sludge distribution again for the resulting facility combination. The blocks "Winter" and "Summer" are used for this optimization, and the same optimal distribution of sludge to facilities and the same total system variable cost are obtained as when the facility combination was generated by Survey.

However, the facility combination may be smaller than the one generated by Survey, because a code number does not record facilities that have zero input in the optimized sludge distribution. This causes no problems with the total fixed charges for the facility combination, due to a special property of the routine COMBEX normally used by Survey to generate all possible combinations of facilities.

Depending on an indicator in the data for the case, Survey will either generate all possible facility combinations using COMBEX or it will obtain combinations from the data itself. Normally COMBEX is used, since only by evaluating all possible combinations can we be sure of finding the global optimum. COMBEX starts with combinations containing the smallest number of facilities, and proceeds to the largest. Thus, a combination whose optimized distribution does not use certain facilities will generally be abandoned because its code number would already have been stored when the smaller combination, not including the unused facilities, was evaluated. Another possibility is that the smaller combination yielded a total system cost too high for consideration and of course, the larger combination with the same facilities being used would cost even more. "Generally" is used because it is possible, through indicators in the data, to instruct COMBEX to include certain facilities in very combination. When using COMBEX, the only facilities with zero input in a facility combination being stored will be facilities included in every combination. If these are not to cause differences in the fixed charges before and after storage as a code number, the fixed charges of facilities instructed to be included in every combination must be zero.

5.7.3 Short runs with specified facility combinations

It is not desirable to use COMBEX, but to have only certain facility combinations evaluated when trial runs are being made to study the effect of a weight factor (section 5.6.1) or some uncertain cost functions. In the latter case, the operation of the program with regard to storage of least cost combinations of facilities might produce unexpected results if facilities with non-zero fixed cost turn out to have zero input and the facility combinations are entered in the data in an unsystematic order. Such results would have a facility combination's stored total system cost larger than the cost calculated at the time of printing out the final list of best solutions, and the solutions in this list may be ranked in the wrong order. It is even possible, if the values of EPS and MAXSOL in the data produce restrictive conditions on the storage of facility combinations, that combinations will be abandoned that really should be stored.

5.7.4 In-process printout

The variable ARBOUT is included in the data primarily to check for such unexpected performance. Every time FACSET (the facility combination counter) reaches a multiple of ARBOUT, an indicator NETOUT is set "true" and this causes the entire distribution for the facility combination to be optimized and printed out before it is screened. This NETOUT is the same indicator used by the block "Results" to have the final solutions printed out.

Even when using COMBEX, it is advisable to enter a value for ARBOUT that will cause a few printouts of solutions that are not necessarily going to end up in the final list of best solutions, just for comparison. However, too many such printouts should not be attempted (i.e., ARBOUT should not be too small) since the amount of paper and computing time used with NETOUT = "true" is quite large.

5.7.5 Controlling program efficiency

Using COMBEX, a computer run can become very long, since all possible combinations are evaluated. For example, if there are 20 potential facilities, there are at most $2^{20} - 1 = 1,048,575$ possible combinations. We say "at most" because COMBEX does not generate combinations that contain facilities that are obviously useless. For example, if a combination contains winter intermediate facilities, but no summer dead-end facilities, the winter intermediate facilities cannot be used because their output would have nowhere to go. Also, if COMBEX is being used, the program reads from the data 4 MAXSIZ values - the maximum number of facilities of each type that should be contained in a combination. For example, if complete decentralization is obviously undesirable, it is realistic to assume that the number of facilities of one type in the optimum solution could not be larger than the number of sources. This rules out many combinations that contain a large number of facilities.

Overriding these two features are any data indicating that COMBEX must include certain facilities in every combination. This does not affect the results if these facilities have zero fixed costs, but it has a very great effect on the number of possible combinations. For instance, in the case of 20 potential facilities, if 5 of them are always included, the number of possible combinations drops to $2^{15} - 1 = 32,767$; about 97% of the previous combinations have been eliminated. Moreover, a fourth feature is available which overrides this; data may be entered saying that certain pairs of facilities should not coexist in any facility combination. For instance, if three facilities A, B, and C actually represent different possible types of facilities at the same location, and it is obvious that no more than one of them could actually exist at the location, then COMBEX could be instructed not to let A and B both occur in any facility combination, nor B and C, nor A and C. This would greatly reduce the number of possible combinations.

Computing time increases not only with the number of facility combinations evaluated, but also with the number of facilities in each combination. Optimization of the distribution for a combination with a large number of facilities takes longer than for a smaller combination. This effect is especially troublesome with linear programming, so the program tries to avoid using linear programming, i.e., subroutine LINPRO, when it is unnecessary. This is the main reason why so much emphasis is put on screening each facility combination as its sludge distribution is being optimized. An important screening feature, which has not yet been discussed, is the unconstrained optimization performed in the block Survey. Here the constraints on the sizes of the facilities are ignored and optimization proceeds by a very simple process. If the total system cost found in this way is greater than C* + EPS, then the cost found with constraints certainly will be also, and the constrained optimization, which requires linear programming, need not be done. On the other hand, if the solution passes this screening, it is then necessary to perform the constrained optimization, unless it is found that no constraints have been violated, in which case the Store block immediately takes over.

5.7.6 The restart feature

Even with all these features it is possible for the program to overrun the time or paper restrictions put on it by the computer; then the program would be abnormally terminated. This means that it may stop in the middle of a case. In order to continue the run without the expense of redoing the whole case, the program needs the values of all the variables used during the execution of a run. Every time FACSET reaches a multiple of IDUMP, which is read in as data for the case, the program writes out this set of values on a dataset called IW2. This should be a tape, disk or card output, so that if the run is abnormally terminated, transport link i. Note that this second method gives the option of entering C_i directly as well, in the guise of d_i, if you indicate a haulage formula with a=0 and b=1.

Method 3. Still more work may be saved if haulage formulas are used, as in the second method, but instead of entering a trip length in the data for each transport link i, just let the computer use t_i instead of d_i where t_i is an approximate trip length, which the computer finds at the beginning of a run as ALPHA times the straight-line distance between the two ends of the transport link. ALPHA is the "travelling factor" that is supposed to convert straight-line distance into actual trip length. The straight-line distance is obtained from (x,y) coordinates for the ends of the transport line; thus, coordinates have to be entered in the data for each source and facility, before any of these case data. These are the parameters for calculating trip lengths that have been referred to above. For a model with 10 sources and 20 facilities this is only 30 pairs of coordinates, which is much easier to put together than 200 or more trip lengths. Note that it may be desirable to use a set of haulage formulas that can compensate for the approximation involved in t_i; therefore, we say the cost function is obtained as $C_i = a_{k_i} + b_{k_i} t_i$ for transport link i, using the haulage formula indicator k_i instead of j_i, since the haulage formula may be different for this link than if the actual trip length d_i was used.

As a simple illustration of the three methods of entering transport cost data, Figure 23 shows the relative location of two sources called w and x and two sinks called y and z. The diagram indicates the transport links by abstract straight lines numbered 1 to 4, rather than by actual travelling routes. In Table 4, imaginary data are shown as set up using the three possible methods, showing how the three methods could yield approximately the same cost functions.

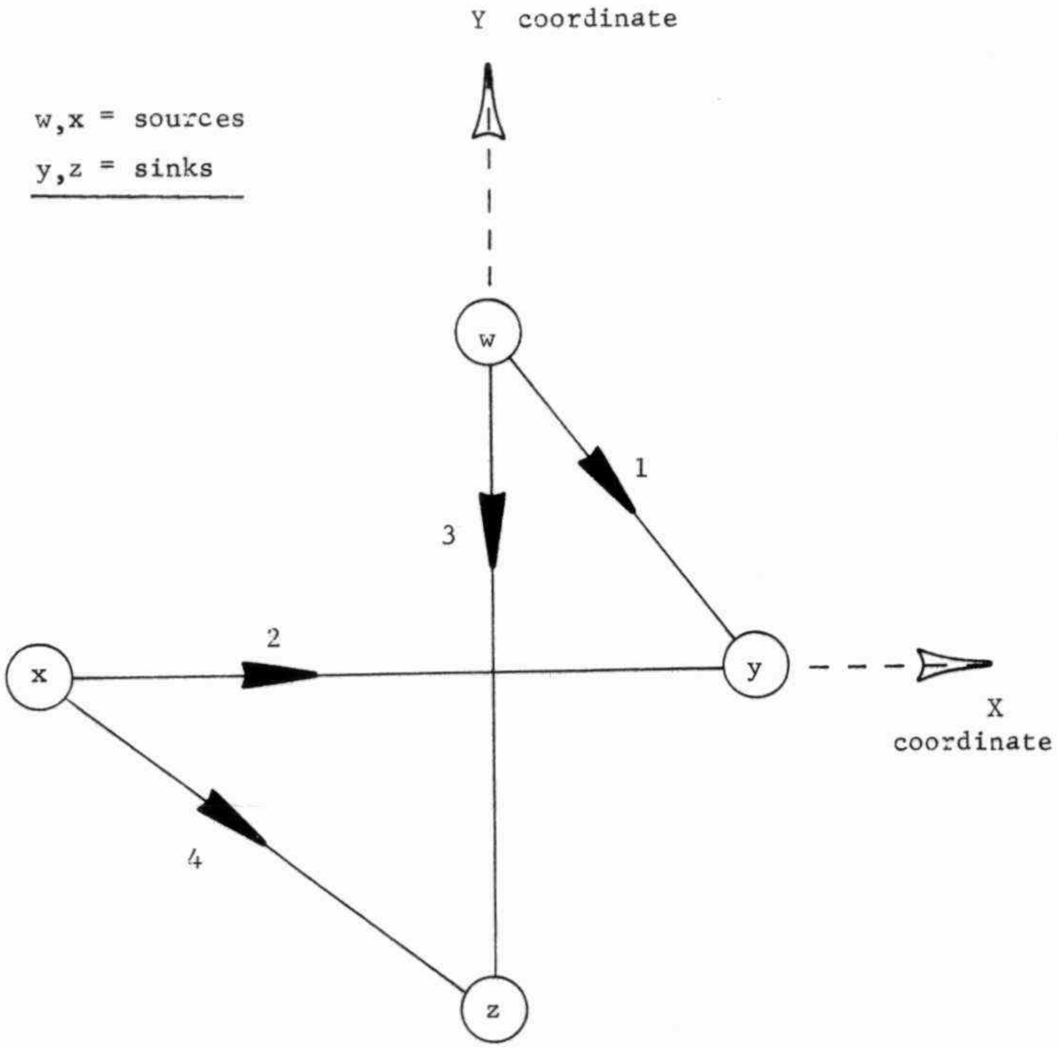


FIGURE 23. TRANSPORT LINKS FOR SIMPLE ILLUSTRATION OF DIFFERENT METHODS TO ENTER TRANSPORT COST DATA

another run can read in the last of these sets of values and continue execution from the point at which it was written out. Thus, no more than IDUMP facility combinations need be re-evaluated. A dataset being read in to continue a previous run is called IR2. As mentioned at the beginning of this section, the program finds out whether or not to read IR2 by reading the title card of the data deck. If the first letters on the card are "REST" as in the title "REST OF RUN NUMBER 100" then the program reads IR2.

5.7.7 Normal termination

After a case is finished, the program prints out some statistics that tell how well the program ran the case: FACSET, NOSMMR, LINCAL, and NSTOR. At this point, FACSET is the total number of facility combinations generated in the case. NOSMMR is the number of times the winter optimization gave the summer system a demand that was impossible to satisfy - this has always been zero in our experience. LINCAL is the number of times the subroutine LINPRO was used, and NSTOR is the number of times the program attempted to store a solution.

A data card is then read to see if another case is included in this run. If not, which is indicated on the card by the first characters "====", the program stops. Otherwise, subroutine START takes over to read the data for another case.

5.7.8 Printout format

The only thing yet to mention is subroutine LAYOUT. This is used to lay out the optimized distribution in an easily-read table and print it out. If the table has a large number of columns, it is divided into parts that are printed one under the other, so that the printout never exceeds the width of a common typewriter-type computer terminal.

6. HOW TO USE THE ALLO2 PROGRAM

The program requires many pieces of information to be fed into it. In this chapter each type of information will be described and suggestions made as to where it may be obtained. The program output will be discussed in Chapter 7, with the examples. The exact format of the program input data is described in Appendix IV. Two basic kinds of data are distinguished - "block data" and "input data".

6.1 Block Data

This is computing system information for the program. It is not required with every run, but only when the program is compiled. It consists of only five numbers that identify, for the program, the following:

IR1 = the computer input file unit which the program is to read as the input data deck (eg. a card Reader)

IR2 = the computer input file unit which the program may have to read as data to continue a previous run (eg. a tape or disc)

IW1 = the computer output file unit which the program is to write on as the printed output (eg. a line printer)

IW2 = the computer output file unit which the program is to write on as data to continue the run if it is terminated (eg. a tape or disc)

INF = the largest integer number the computer can normally store and work with without causing overflow error.

These five numbers, which will be readily available to anyone familiar with the computing system, are entered via the "block data" subprogram when the program is compiled. See Appendix V for full details. The datasets IR2 and IW2 were discussed in the preceding chapter. IR1 and IW1 are self explanatory. This chapter deals only with INF in block data.

6.2 Input Data for a Run

This is information to be included in the data deck for every run. Each type of information will be discussed in the order it would occur in the data deck.

The first thing is the number of sources in the model. This is from five to ten in a typical regional problem. Sources that are relatively small should not be included in the model, and sources that are very close together, so that their transport link cost functions are virtually identical, should be merged in the model. The smallest number of sources that gives the model sufficient realism should be used, since the distribution optimization process takes longer for a larger number of sources. With its current dimensions for computer storage space, the program can handle up to ten sources.

The number of potential facilities can be up to about 30. Reasonable computing times (eg. two minutes per case) have been obtained with 27 facilities, in which 16 were included in every combination for a model with six sources. Large numbers of potential facilities require significantly more computing time. With its present dimensions for computer storage space, the program can take in up to 30 potential facilities. The limit on the number of deadend facilities of each kind is 20, while the limit on the number of intermediate facilities of each kind is 10.

An additional limit is posed here by INF, since the program calculates the number 2^{NF}, where NF is the total number of potential facilities. Obviously NF must be small enough to satisfy the condition $2^{NF} \leq$ INF, or overflow error will result.* Overflow of the quantity 2^{NF} is not serious and would not cause a faulty run, but overflow of $2^{NF} -1$ would affect the storage of facility combinations by code numbers.

For each source and potential facility the program requires an abbreviated name. Internally the program identifies each source or facility by a number; but in the printout, wherever any sources or facilities are mentioned, the appropriate abbreviated names appear along with the numbers in order to enhance legibility. Each abbreviated name consists of four characters, which may consist of numbers, blanks, and punctuation marks, as well as letters. For example, suitable names for a drying lagoon located at a place called Dagby might be "DGDL", "D8.L" or "DGL". The idea is to make it easy to recall what the abbreviation stands for and to distinguish it from other facilities or sources.

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* Note that 2^{30} = 1,073,741,824 and this is larger than INF on some small computing systems.

6.2.1 Transport cost data

The information discussed so far remains the same for all cases in a run. Further information of this type are parameters for calculation of trip lengths, and parameters for restricting storage of solutions.

The parameters for calculating trip lengths are required only if a case in the run requires trip lengths calculated by the program in order to get transport link cost functions. It must be explained at this point that the transport link cost functions in a case can be obtained by the program from the case data in three ways. An indicator in the case data itself tells the program which of the ways it is to use for that case. The three ways are*:

Method 1. For each transport link i, the slope C_i of its cost function can be entered directly in the data.

Method 2. Since in reality C_i may have to be calculated for each link from a haulage formula and a known trip length for the haul, considerable work and possible error may be saved by having the program do these calculations for you. After all, if there are 10 sources and 20 facilities, then there are 200 transport link cost functions without counting those from the intermediate to the dead-end facilities. It is much easier to indicate which haulage formula to use for each of these, than to actually do the calculations. A haulage formula j is of the form $a_j + b_j\ d$, where d is the trip length for a transport link, and a_j and b_j are the haulage formula coefficients. With its present computer storage space dimensions, the program will accept up to nine different haulage formulae or (a_j, b_j) pairs. For each transport link i, the slope of its cost function is obtained as $C_i = a_j + b_j\ d_i$, where j_i and d_i are entered in the data for each link to indicate which haulage formula to use and what the trip length is, respectively. We call j_i the haulage formula indicator for

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* Whereas a transport link is usually identified by a double subscript to indicate the two ends of the link, here only a single subscript is used for simplicity.

TABLE 4. SIMPLE ILLUSTRATION OF COST DATA USING THREE DIFFERENT METHODS FOR THE TRANSPORT LINKS IN FIGURE 23.

DATA | **EFFECT**

METHOD 1:

Case Data:	from w	from x
C: unit cost to y	2.86	2.62
C: unit cost to z	2.52	3.50

$C_1 = 2.86$ (\$/cu yd)
$C_2 = 2.62$
$C_3 = 2.52$
$C_4 = 3.50$

METHOD 2:

Case Data:

Haulage formulas: if j = 1 then a = 1.03, b = 0.03;
if j = 2 then a = 0.88, b = 0.032.

	from w	from x
j: formula to y	1	2
d: trip length to y	62	54
j: formula to y	1	2
d: trip length to z	50	82

$d_1 = 62$ (minutes)
$d_2 = 54$
$d_3 = 50$
$d_4 = 82$
$C_1 = 1.03 + 0.03 \times 62 = 2.89$
$C_2 = 0.88 + 0.032 \times 54 = 2.61$
$C_3 = 1.03 + 0.03 \times 50 = 2.53$
$C_4 = 0.88 + 0.032 \times 82 = 3.50$

METHOD 3:

Run Data: ALPHA = 3 real minutes per "mile as the crow flies"

co-ordinates:	X	Y
w	0	12 (miles)
x	-16	0
y	9	0
z	0	-12

$t_1 = 15 \times 3 = 45$ (minutes)
$t_2 = 25 \times 3 = 75$
$t_3 = 24 \times 3 = 72$
$t_4 = 20 \times 3 = 60$

Case Data:

Haulage formulas: if k = 1 then a = 1.1, b = 0.04;
if k = 2 then a = 1.1, b = 0.02.

	from w	from x
k: formula to y	1	2
k: formula to z	2	1

$C_1 = 1.1 + 0.04 \times 45 = 2.90$
$C_2 = 1.1 + 0.02 \times 75 = 2.60$
$C_3 = 1.1 + 0.02 \times 72 = 2.54$
$C_4 = 1.1 + 0.04 \times 60 = 3.50$

Consider the data shown under Method 3 first, as this is the least work for the user. The coordinates of the four points are entered, along with the factor ALPHA that is to convert miles "as the crow flies" to minutes for an actual return trip. This conversion factor is just an average: it yields values of t that are too small for links 1 and 4 but too large for links 2 and 3. This is compensated for in the values of b in the different haulage formulas. The data would be entered without calculating values for t or C, only using rough judgement to be able to say that the computer would come up with fairly good values of C.

If more work is possible, a significant improvement in precision is usually achieved by entering the trip length for each link in the data, as shown under Method 2. Then the haulage formulas can be completely devoted to represent finer details in costs than a coarse correction for ALPHA, and neither ALPHA nor the coordinates are used in the data. The data are entered without calculating values for C, as the trip lengths and haulage formulas should be trusted to yield good values in the computer.

Finally, if precision is of the utmost importance and work does not matter, each value of C can be entered directly, as shown under Method 1. This requires many calculations that could probably be done by the computer.

As discussed in Appendix III, typical values for a and b have been found to be about 1 and 0.1, respectively, for trip length in miles and C in dollars per cubic yard. However, the variation from one region to another is very large and a dependency on the water content of the sludge may also exist (haulage by dump truck has been found to be slightly cheaper per unit volume than by tank truck). In regions with a lot of traffic, haulage formulas may be better expressed with trip lengths in units of time rather than distance. Of course, haulage formulas can also be used for transport links representing transport by rail or pipeline as well as truck or any other method.

Whether a haulage system is owned regionally or privately, the transport link cost functions will involve a high degree of uncertainty, since the total amount of transport equipment and labour used by the system will affect them, and this is not known until the optimal sludge disposal system is found and a transport schedule created to achieve the desired distribution of the sludge. Therefore, the computer program should be run with several different estimates. This is especially easy with the second and third method described above since only the haulage formulas need to be changed, not the data for each transport link.

For truck haulage a fairly good starting point can be obtained using the current rates for truck rental and driver wages. For example, if the average truck capacity is 10 cubic yards, the total of rental plus wages is $30 per hour and the average road speed is 30 miles per hour, then we can use $b = \frac{30/30}{10} = 0.1$ dollars per cubic yard per mile. This is just the part of the unit cost chargeable to trip length. All the rest must be expressed by the coefficient a. The cost of daily travel from the truck depot and back can be ignored, compared to the cost of several hauls in a day. However, suppose the loading and unloading time for each haul is 20 minutes, then $a = \frac{30 \times 20/60}{10} = 1$ dollar per cubic yard.

The above explanation of the transport data is concerned mostly with data that are included in each case, and can be changed with each case in a run. Only ALPHA and the (x,y) coordinates are entered in the data before any of the cases, and this is required only if any of the cases uses Method 3 for obtaining cost functions.

6.2.2 Solution storage parameters

The last type of information that is the same for each case in the run is the pair of numbers, EPS and MAXSOL, that the program needs for restricting the storage of least cost facility combinations. As discussed in the preceeding chapter, EPS is the maximum difference allowed in the total system cost, between the current cheapest combination stored and a combination currently under consideration, if this combination is to be stored in the list of current cheapest combinations. MAXSOL is the maximum number of combinations of facilities that this list may contain. With its present computer storage space dimensions, the program will accept any number for MAXSOL from 1 to 20.

6.2.3 Source and facility data

For each case in a run, the important parts of the data are the output of sources, the characteristics of potential facilities, and the transport cost functions.

The total output of a source is just the annual production of sludge that the disposal system must handle. This is closely related to the population the treatment plant serves and the type of process it uses. As a starting point, the production in recent operations records may be used. Any change over recent years can be made for data cases representing future points in time. Care must be taken to predict any future changes in the plant process that will affect sludge production, such as nutrient removal.

Sludge quantities must be expressed in units compatible with the units used to express the slope of the cost functions. For example, cubic yards are compatible with dollars per cubic yard. Units of weight rather than volume may also be used, such as tons, especially if it is found that cost functions are more accurately expressed in terms of weight. Units can also be used that measure only a component of the sludge, such as tons of dried solids. When using anything other than volume units, special care must be taken to give the intermediate facility "volume reduction factors", values that will produce the correct ratio of total quantity out over total quantity in.

The choice of units is somewhat restricted by INF. The program is designed with the expectation that the slopes of all cost functions will be between about 0.0001 and 10.0. However, it must work with fairly large integers (eg. larger than 100) to use the transportation method of linear programming accurately; so when it receives all the cost function slopes and calculates the value of B + C for each transport link, it immediately multiplies all these values by 10,000,000. Therefore, units that will make any of the values of 10,000,000 x (B + C) more than INF must not be used.

Furthermore, as seen in Chapter 4, the program obtains the total system cost by summing several products of quantity times cost per unit quantity, and the result must never exceed INF. The choice of units must give no chance of violating this rule with optimal or near-optimal solutions. The program itself will assure that the rule is not violated for nonoptimal solutions, since it is able to scale down sludge quantities for its computations and, if necessary, it also scales down the values calculated for 10,000,000 x (B + C). The program is designed to expect sludge quantities (i.e., production of individual sources; size limits on facilities) to be entered in the data as numbers in the range from about 1000 to 100,000,000. It employs a scaling routine* that scales down the numbers as little as possible while ensuring safety from overflow problems. All results in the printout are scaled up again so that the program user can generally ignore the fact that scaling has occurred. However, the printout shows the factor used for division of sludge quantities, and the factor used for multiplication of B + C (net multiplication after multiplication by 10,000,000 and possible subsequent scale-down), as well as the scale factor (which may be less than one) used for multiplication of facility fixed costs for consistency. This information may be useful for understanding the small round-off errors that can cause a barely noticeable disagreement between results of cases that use the same input data expressed in different units.

Returning to the discussion of specific input data, we shall proceed with the information required for each potential facility. First of all, there is the size limit in terms of total annual input. This may be used to avoid consideration of a size larger than is physically or politically possible at the facilities' given sites, to avoid consideration of expanding an existing obsolete facility, or to avoid consideration of a size beyond the range of validity of the facility's given cost function, as well as to represent a point in the cost function where the cost actually soars straight up. If there is no practical size limit on a facility, this information may be left blank, in which case the program assigns a number which is at least as high as the source production summed over all sources. It is necessary to have such a number to have the transportation method of linear programming operate properly; the special number the program uses is the lowest such number which has all its digits the same. This special property makes it clear, in the printout where the input data is reproduced, which facilities have been entered with no practical size limit. In addition, any facility entered with a size limit that is excessively large, that is, larger than this special number, has its size limit replaced by this number.

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* The routine is described in detail in Appendix V.

The next facility characteristic required is the volume reduction factor. Of course, this is meaningful only for intermediate facilities. For other facilities, this information may be left blank. Typical values are (in volume units) 0.8 for storage lagoons, 0.25 for vacuum filter plants and 0.05 for a combined filter and incinerator. Operations records are the best source for this information. Numbers larger than one are also acceptable as might occur if an intermediate facility represents a biological treatment plant.

Then there are the coefficients A and B of the facility cost function, where A is the fixed charge and B is the slope of the curve. We recognize that facility cost is usually calculated as the sum of two subtotals, one of which represents the total equivalent annual capital cost, and the other the total annual cost of operating and maintenance or "O and M". Therefore, the program is designed to accept, for each facility, one pair of coefficients A_1 and B_1 for capital cost and a second pair A_2 and B_2 for O and M cost. In effect, two cost functions are entered, the sum of which gives the total facility cost function: the program immediately calculates $A = A_1 + A_2$ and $B = B_1 + B_2$. Note that A_1 and A_2 must be integers or zero, since non-zero fixed charges are at least $1,000. This method of entering the data facilitates changing a facility cost function from one data case to another; frequently, it is desirable to determine the effect on the results if just the O and M costs are changed, or if just the capital costs are changed.

The cost functions are usually quite easy to find for a certain type of facility and capacity. The independent variable or the horizontal axis is the total input in one year (must be a quantity in the proper units); the total O and M cost at any point on the curve is primarily the total materials, chemicals, power, maintenance, parts and labour required to process that input. For the capital cost function, the independent variable or the horizontal axis is also the total annual input, while the capital cost at any point is the equivalent annual capital cost of a facility at that input. Keep in mind that facility capacity, measured in terms of input per day, must be converted to actual total input over the whole year, for purposes of the cost functions. This will involve multiplication by a daily operating factor as well as the number of days in the year that the facility is used.

The capital cost should be in terms of equivalent annual cost. Any book on engineering economics will show several different ways of calculating equivalent annual cost, each giving a different result. We believe that the best method in this application is to take the total present value of all expected cash out flow for capital expenses and loans, and divide it by the number of years of expected life of the sludge disposal system*. Unless the facility would have an "infinite" life (as a lagoon might), the cash flow should include a sinking fund or other provision for eventual replacement of the facility, assuming that it is desirable to have the facility available "forever" once it is built. Such a provision should also be included if it is obvious that the facility would require upgrading or expansion at some point in the future. On the other hand, it is possible that for some reason, such as the increasing value of the land at the locality of the facility, or increasing cost of transportation to the facility, it would be advantageous to retire the facility after the current period and plan a different sludge disposal system for the next period. Then the cash flow for the current period would include no provision for facility replacement, unless such was necessary within the period; but it would include an incoming credit for the sale or salvage of the facility upon retirement.

A potential facility that represents an existing facility should not have capital charges included in its cash flow that are properly charged to a past planning period. For instance, if a facility is chosen to be built in the current planning period, the whole initial cost of the facility should be charged to the current system, even if the payments on a capital loan extend into the next planning period, since these payments have to be made during the next period whether or not the facility is used. However, in the data case for the next planning period, the existing facility could have included in its outward cash flow any lost benefits that would be caused by using the facility rather than retiring it - such benefits as credit for sale or salvage.

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* By "life of the system" we mean the period over which the optimal combination of facilities produced by the model would remain essentially unchanged; or the period after which a new planning period entailing a different case of data would start.

When running data cases representing a system at different points in time, assumptions must be made, before the optimal combinations are known, as to what facility will be used in each time period so that their existence can be used in making up capital cost functions for them in the next time period. Since the optimal combination of facilities may depend on these assumptions, and the correctness of the assumptions may depend on the optimal combinations, a series of trials should be made, modifying the assumptions until they appear correct in light of the planning solutions.

For basic ball park estimates of average capital and O and M costs of facilities of various sizes, the 1971 Black and Veatch report for the U.S. EPA might be used. The pertinent material from the report is given in Appendix III. Costs can vary a great deal with locality, because of the labour situation and special problems with foundations, supplies and land costs, and with time (to be considered in data cases representing time in the future), inflation and changing supply and demand conditions have a major effect. All told, precise estimates cannot be expected for constructing facility cost functions. The effect of uncertainty should be studied by making several runs with variations in the cost functions.

Before leaving the subject of facility cost functions, we shall discuss the technique you may use to handle some of the types of functions which are uneven. When you calculate facility costs for different total inputs and plot the points obtained, it is sometimes impossible to fit a single straight line to the points satisfactorily. When this happens, you can represent the potential facility by two potential facilities at the same location: one with a cost function valid for low total inputs, and the other with a cost function valid for high total inputs. The idea can be extended to three facilities representing three total input ranges, and so on.

For example, it is common to plot capital cost versus input for an existing facility as shown in Figure 24. The capital cost of the existing facility is nothing, as long as the total input is less than the present capacity, except for the forfeited credit that would come from salvaging the facility if it were not used. For total input larger than the present capacity, the capital cost is calculated on the basis of expanding the existing facility so that, at this point, the curve takes a jump. Such expansion may incorporate the existing facility, or just part of it, or replace it entirely; you will have had to choose among these alternatives, possibly in different ways for different total input values, to do your cost calculations. In any case, the jump is too large to permit a satisfactory approximation by a single straight line from zero total input right up to the size limit of the expanded facility (see dashed line in Figure 24). Instead, you fit two different straight lines to the group of calculated points. This implies two separate potential facilities at the same location: the existing facility with a size limit equal to its present capacity, and an expanded facility with a larger size limit and cost function that are valid for total input larger than the size limit of the existing facility. Since the program will not accept a size minimum for a facility, you hope that the total cost function (capital plus O and M) for the expanded facility will be higher than that for the existing facility, for all total input values smaller than the size limit on the existing facility, so that the program will automatically prefer the existing facility for these smaller values.

You may proceed now to fit two straight lines to the calculated O and M points, dividing the lines at the same value of total input as for the capital cost, as shown in Figure 25. Suppose this introduces a downward jump in the curve, as shown, since the O and M for the old existing facility is not economical when operating near capacity. In other cases, you might have got an upward jump, or no jump at all.

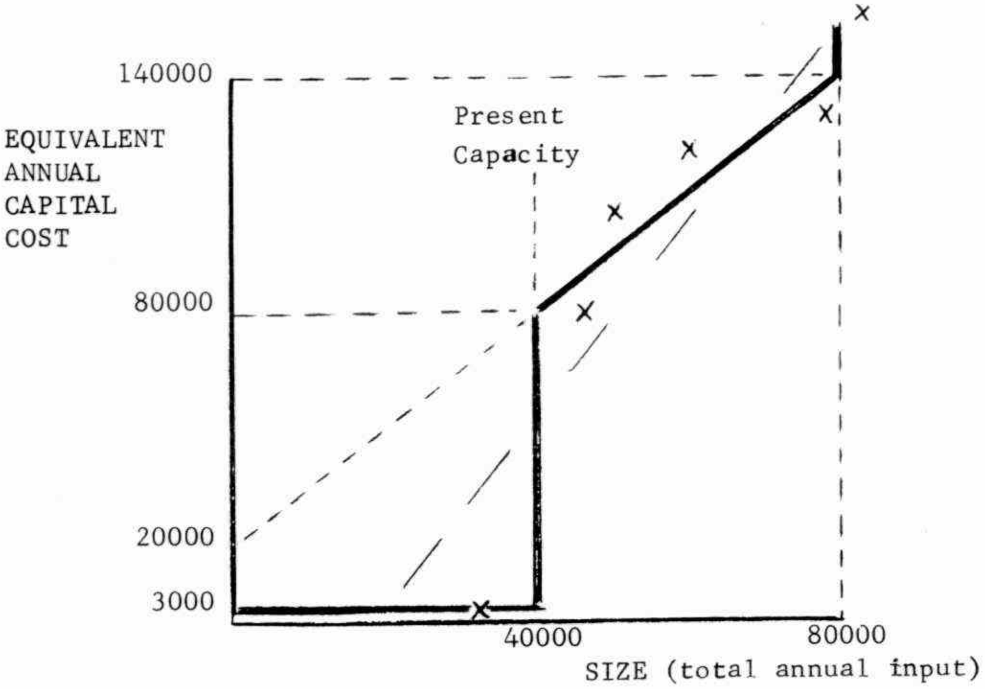


FIGURE 24. CAPITAL COST PLOT ILLUSTRATING DISCONTINUITY OWING TO EXPANSION OF EXISTING FACILITY

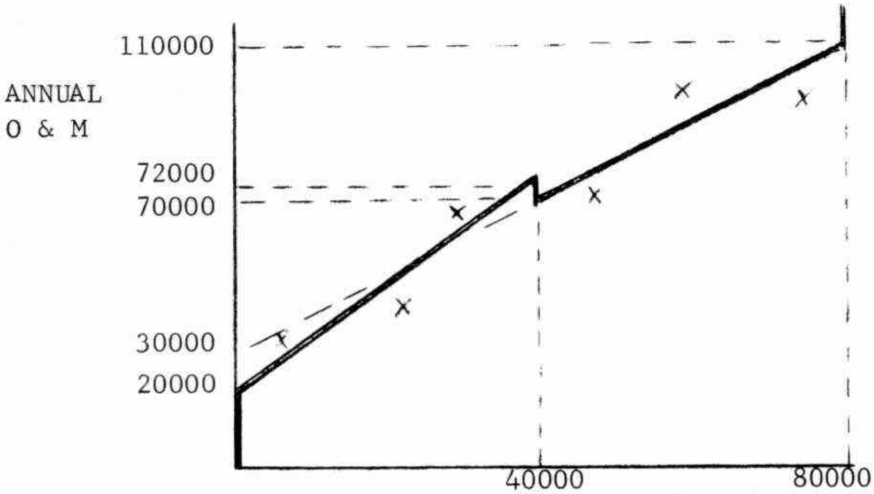


FIGURE 25. PLOT OF OPERATING & MAINTENANCE COST FOR FACILITY IN FIGURE 24

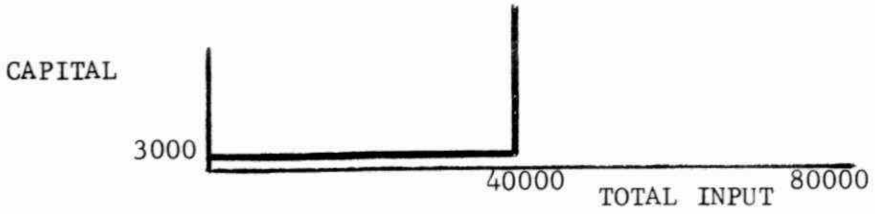
For separated existing and expanded facilities you can now make cost functions as shown in Figure 26. The curves for the existing facility are just the left-hand parts of the curves in Figures 24 and 25; for the expanded facility they are the right-hand parts in Figures 24 and 25 extrapolated back to the vertical axis.

By adding the curves for each facility together you find that the existing facility definitely is cheaper for all values of total input from zero to its size limit. So there is no problem. If you find that the expanded facility was cheaper for some values just under the size limit of the smaller facility, you could just decrease that size limit to the turning point where the existing facility became cheaper. On the other hand, if you found that the expanded facility was cheaper for some values just around zero, you would have to refit or tilt the curves slightly so as to eliminate that problem.

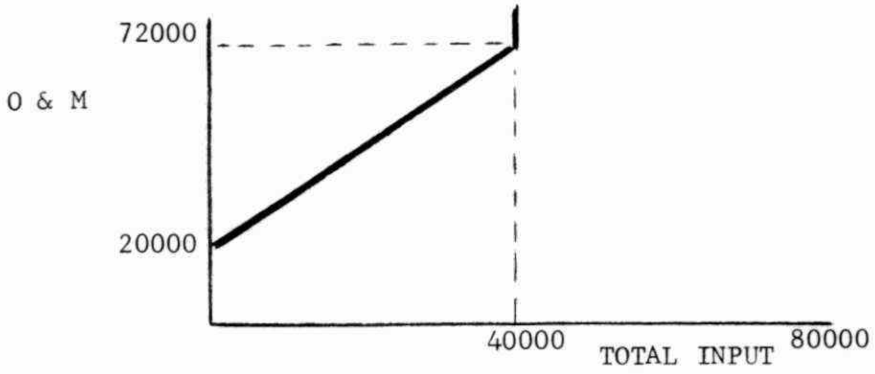
In the very unlikely case that the expanded facility appeared cheaper than the existing facility for a majority of total input values between zero and the present capacity of the existing facility, you should investigate the actual cost of replacing the existing facility for low total input values, as opposed to the cost obtained by the backward extrapolation of the higher curves, before you decide to immediately scrap the existing facility.

A simple check to perform when considering the representation of uneven or discontinuous cost functions by separate facilities is to see if the discontinuity in total cost (capital plus O and M) is as significant as in the subtotal (capital or O and M, as the case may be). If not, it may be sufficiently accurate to fit a continuous straight line for the total cost function, recalling that the program only uses total facility cost in its computations anyway. It saves a great deal of computer time if you use one potential facility in place of two. After fitting the total cost function curve, you could then apportion it arbitrarily between two imaginary continuous cost functions representing capital and O and M for submission to the program - ALLO2 would not know the difference.

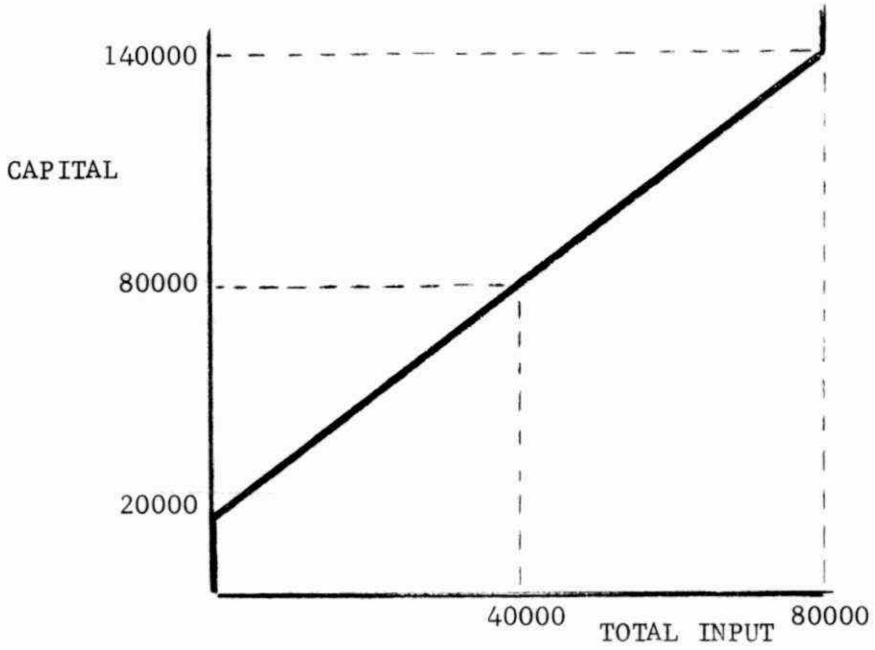
(a) Capital for Existing Facility



(b) O & M for Existing Facility



(c) Capital for Expanded Facility



(d) O & M for Expanded Facility

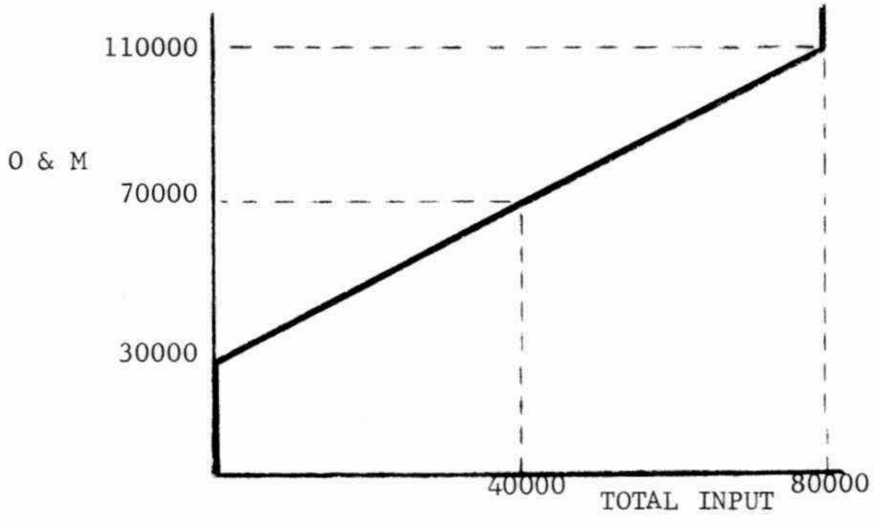


FIGURE 26. COST FUNCTIONS FOR EXISTING AND EXPANDED FACILITIES REPRESENTING ONE FACILITY

In fact, whenever you feel you can get a better curve fit to total cost rather than to the capital and O and M subtotals, you should do it and then re-apportion the curves between capital and O and M. You could even tell the program the total cost is all capital or all O and M, but then it would be harder to make up new data cases that contain variations in estimates of just capital or just O and M.

6.2.4 Model structure in a case

After the information on facility characteristics, the program needs to know whether the model includes transport links from sources directly to all-year dead-end facilities. This question can be answered by saying whether there is any all-year dead-end facility in the model which may be permitted to receive sludge directly from a source. The option to deny these transport links was made available since it often occurs that, due to regulations, landfills are not permitted to receive liquid sludge. Rather than make the size limit of the facilities zero, or all the unit transport cost infinity, it is more efficient to just take the transport links out of the model.

Next, the program must be told what fraction of the year is "winter", i.e., what fraction of the year the summer dead-end facilities cannot be used (due to regulations, ground conditions, weather, etc.). This must always be more than zero, since, if the summer dead-end facilities could be used the whole year, they should be called all-year dead-end facilities. The maximum value for this fraction is 1, which is used if there are no summer dead-end facilities in the model.

6.2.5 Transport cost data for a case

At this point, the program needs to know which of the three methods of entering data for transport cost functions is to be used in the case to be run. You will recall the discussion of these three options from Section 6.2.1. After the choice is made, the transport data are entered. First, if haulage formulas are to be used, the two coefficients a and b for each formula are entered. Then, for each transport link from sources to facilities, one or two numbers are entered. If "Method 1" is being used, then just the value of C is entered for each transport link.

If "Method 2" is being used, then the value of j, representing the subscript on a and b and thus identifying the haulage formula to be used, is entered along with the value of d or trip length. If "Method 3" is being used, then just the value of k, identifying the haulage formula to be used, is added to the case data.

After the transport links from all sources to all facilities are done, then those from winter intermediate facilities to summer dead-end facilities are entered, followed by those from all-year intermediate to all-year dead-end facilities. Information must be entered for every possible transport link between the two sets of points in each of these three groups of data. The only way of ruling out a transport link is to make its cost much higher than any of the rest (within the restrictions imposed by INF, as discussed previously). The only exception to this is when all transport links from sources to all-year dead-end facilities have been disallowed; then the information for these links can be left blank, even though there are spaces for them in the data.

6.2.6 Weight factor and running mode

The next item the program needs to know is the value of the weight factor F to be used in the case. You will recall from Chapter 5 that this is used to bias the optimization of sludge distribution with respect to the demand placed on summer dead-end facilities. So if there are no summer dead-end facilities, this can be left blank. Usually zero is a good value to try for this parameter, and a couple of values either side of zero should be tried as well. Of course, these trials can be made without making the program run through all possible combinations of facilities in its procedure to find the optimal combination. In fact, the next information the program requires is just how many combinations of facilities are stated in the input data; a blank or zero for this tells the program that it is to generate all possible combinations itself, rather than just take some combinations from the data. Therefore, this information would be left blank if it was desired to have the program find the optimal combination among all the possibilities. When a data deck is first set up, it is advisable to make a run with just one or two combinations of facilities entered in the data, in order to check on whether the data deck has been set up correctly. Further short runs should be made to determine the effect of the weight factor. The facility combinations used in these preliminary runs can be any of those of particular interest, such as combinations that intuitively look as though they would be close to the optimal. It is especially useful to see the results for the facility combination that contains every potential facility in the model: the optimal distribution for this combination would be the global optimum if there were no fixed charges in any of the cost functions.

6.2.7 Output parameters

The program requires the two numbers ARBOUT and IDUMP. The functions of these were discussed in Sections 5.7.4 and 5.7.6, respectively. If the preceding information entered, namely the number of facility combinations to be run in a case, is greater than zero (and not blank), then ARBOUT should be 1 and IDUMP should be some number, say 1000, that is larger than the number of facility combinations. ARBOUT is set at 1 because, assuming there are just a small number of specified combinations, it is probably of interest to see the optimized distribution of every one of them before they are screened. IDUMP is set higher than FACSET could ever reach so that no data dump occurs: the amount of output produced by the dump would cost as much as to redo an abnormally terminated short run from the beginning and it is extremely unlikely that abnormal terminations would occur due to excessive run time or printout anyway. The program prints out the optimized distribution of every ARBOUTth facility combination, suspending screening until this printout is finished: about one page of printout is used every time this happens. On the other hand, the data dump routine produces about 300 cards of output after every IDUMPth facility combination; therefore, IDUMP is to be used with much discretion.

When doing a full run, i.e. with evaluation of all possible facility combinations, the number of combinations that will be evaluated must be estimated so that ARBOUT and IDUMP can be set with some idea of how much output they will produce. A fairly close overestimate is obtained by raising 2 to the power "total number of potential facilities in the model, minus the number of facilities that will be included in every combination". For example, if this estimate is 5000, then reasonable values for ARBOUT and IDUMP would be 800 and 1800, respectively. One normally wants to see five to ten printouts of optimized distribution before screening, and two or three dumps of data for continuing a terminated run.

6.2.8 Data to control program efficiency

Next the program can accept, if you wish, a number to be used as an initial value for C* in the case being run. If many runs with similar data have been made (including runs that did not make a full survey), you can use a number slightly higher than the highest cost of any near-optimal combination observed in the results from those runs. This would significantly speed up the screening process for the program. However, if a good feeling for the cost of near-optimal solutions has not been acquired, it is best to play safe, avoid the danger of setting the initial C* so low that no combination found by the program can be stored, and leave this information in the data blank. In that case the program will start with C* = INF.

If combinations of facilities are to be entered in the data, a list of them is the only information left to be entered for the case. Otherwise, the program must be informed of any time-saving restrictions on the set of all possible combinations which it will evaluate. First, any facilities that are to be included in every combination are entered in the data. All facilities which have no fixed charges should be included in this, unless they appear in the next restriction. The next restriction is a list of all pairs of facilities that must not occur in any combination. This was discussed in Chapter 5. Any facility that appears in this list should not appear in the above set of facilities that are always to be included, since that would either be a contradiction or it would force some facilities to be always excluded. The only information left to be entered for the case is the maximum number of facilities of each kind that is worth looking at in one combination. These four numbers are generally set according to some judgement as to the largest most decentralized sludge disposal system that could conceivably be competitive with the optimal combination.

6.2.9 Summary

Now we have finished describing the information required for each case being run. You will find that, after one case has been set up, it is not really much work to set up another case. Usually most of the information is the same in each case, even between different runs. The most efficient way of setting up the data deck for a new case is to reproduce the deck from a similar previous case, using a data processing program to modify the numbers that need changing. Without a data processing program, it is just a little more work to make the desired changes by hand.

7. EXAMPLES

Two examples are given in this chapter. The first is very simple and is intended to illustrate how to assemble a model and formulate the input data for the program. The second example is part of an actual study made on the Regional Municipality of Niagara, presented here to illustrate the program output and its interpretation, and also the types of preliminary runs and different data cases that may be made.

7.1 Simple Example

The imaginary Regional Municipality of Cowtown has five sources of liquid sludge that currently produce a total of 86,000 cu yd per year. A map of the region with pertinent features is shown in Figure 27. The amount produced by each source, both currently and as predicted for the future, is shown in Table 5. The table also shows suitable abbreviations for the source names. At present, the largest source has an on-site (in-plant) sludge dewatering facility, and this dewatered sludge is hauled to a distant landfill known as Mogul Hill. The other sources dispose of sludge by contracting haulers who ultimately spread it on agricultural land. As urbanization and source production increase, the agricultural land available for land spreading is becoming scarcer and contractors' fees are going up. Therefore, the regional pollution control engineer is awarded the task of planning a long-range overhaul of the sludge disposal system.

TABLE 5. SIMPLE EXAMPLE SOURCE PRODUCTION (cu yd/year)

Pollution Control Plant	1976	1980	1990
Cowtown (CWTN)	52,000	85,000	100,000
Pigden (PGDN)	9,000	22,000	30,000
Sheepville (SPVL)	19,000	29,000	40,000
Sewerpipe (SWPP)	5,000	11,000	30,000
Fencehole (FNCL)	1,000	2,000	5,000
Total	86,000	149,000	205,000

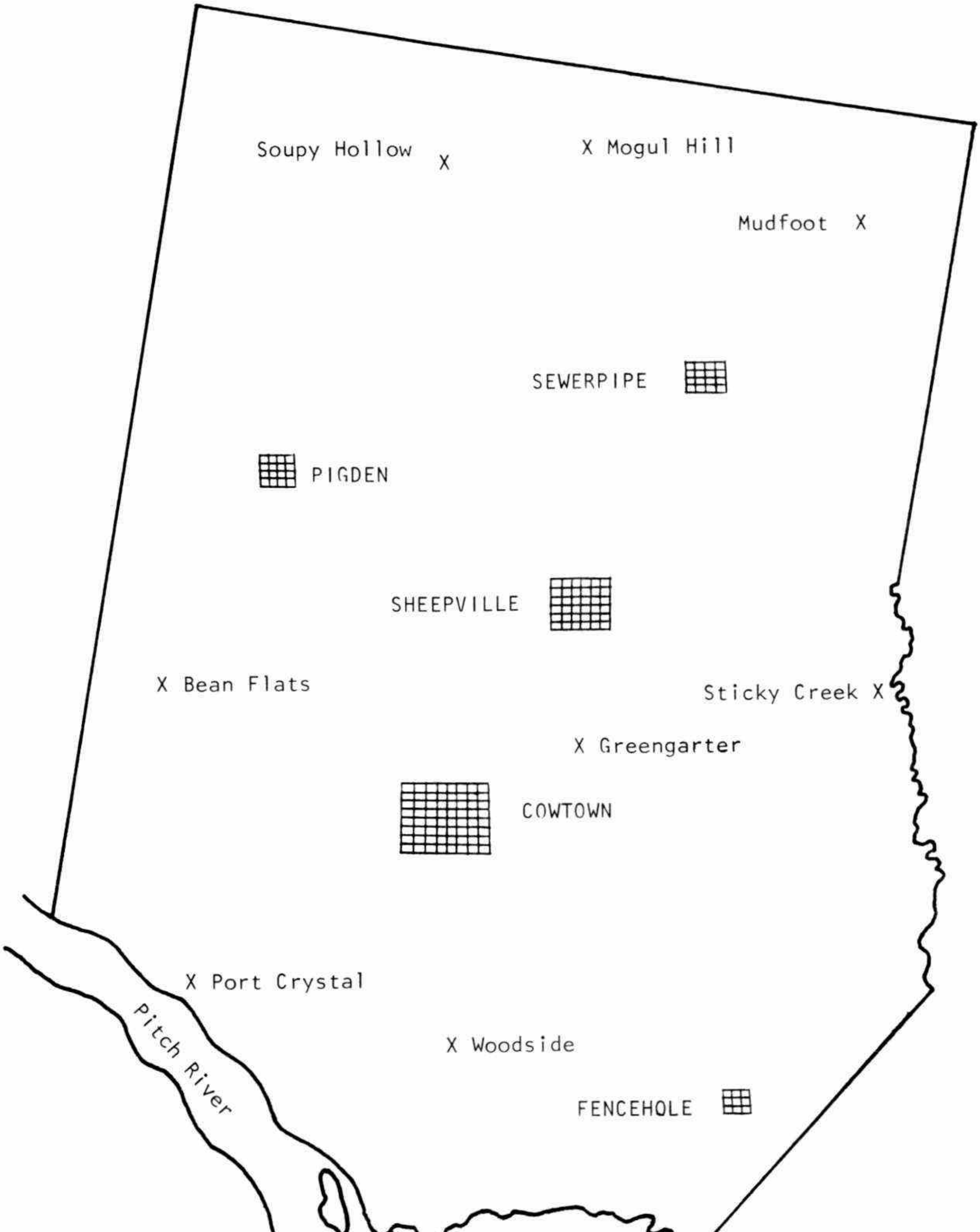


FIGURE 27. IMAGINARY REGION IN SIMPLE EXAMPLE.

The first thing to do is decide on a set of potential facilities for the model. Suppose you are in charge of this project. You will include the existing landfill at Mogul Hill, since it will still be serviceable for a number of years. However, suppose Mogul Hill is a well-established facility that, due to its accumulated height, can only accept solid waste; whereas you would like to look at the possibility of a landfill where liquid sludge can be dumped and mixed with refuse or other solid waste without creating excessive runoff or structural instability in the fill. You find a site suitable for such a new landfill just four miles from Mogul Hill, at Soupy Hollow. The land is obtainable at reasonable rate and the public could look forward to having someday, not just one ski hill in that area, but two (that is, if you actually decide to implement the new landfill, which is at this point just a potential facility).

Next you do some rough calculations to find the cost functions for the landfills. There is no capital cost for Mogul Hill since it already exists and operates, and even if it is no longer used for sludge disposal it cannot be profitably retired since it is still good for refuse disposal. The O and M costs for Mogul Hill can be accurately estimated using past records.

The capital costs of Soupy Hollow are estimated on the basis that a certain overhead of land and excavation machinery is required no matter what the size of the facility is; and then land is required and an initial trench must be prepared in proportion to the annual total input to the facility assuming a fill depth build-up rate of one yard per year. You decide to include a safety margin in the land required so that the actual capacity of the facility is always 20% larger than any given total input. The percentage of input that is liquid has some effect on the capital cost, since the percent solids affects the fill depth build-up rate, and also has some effect on the O and M cost owing to handling of the liquid and mixing solid waste into it. You decide to assume that half of the sludge input to the facility would be liquid, and that sufficient other solid waste would be readily available for mixing, so that you can estimate the fill build-up rate and the man hours required for this handling job for any given total sludge input

The calculated points and fitted curves for the cost functions are shown in Figure 28.

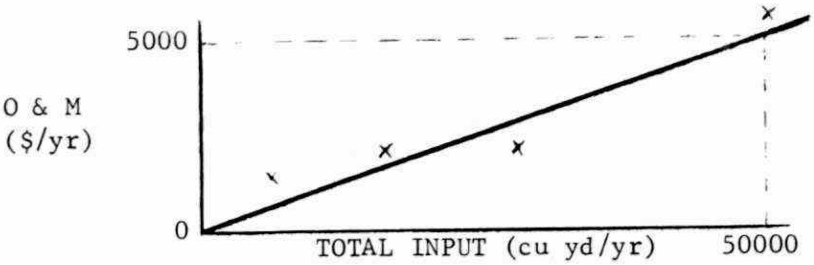
While looking at the sensitivity of the Soupy Hollow cost functions to the assumption regarding the proportion of liquid sludge, you decide that a total liquid sludge input of over 50,000 cu yd/year would be unmanageable, or at least put serious doubt on the validity of the cost functions. Therefore, you put a size limit equal to this amount on the Soupy Hollow landfill. Recall that a size limit on an all-year dead-end facility applies only to input received directly from sources.

For the Mogul Hill landfill the size limit must effectively be zero; but you would not obtain the desired effect by saying zero because the program would then assume that you want no limit at all (it does this because, with any other kind of facility than all-year dead-end, a facility would not be put in the model if it really had a size limit of zero). You can accomplish the desired effect by saying the size limit is just one cu yd/year, which is virtually zero compared to any other volumes you will be dealing with; it is possible that the solutions would then actually send one cu yd/year which of course can be ignored, from some source to Mogul Hill. Another way of handling this problem is to make all transport fees from any source to Mogul Hill extremely large. The transport cost functions will be discussed later.

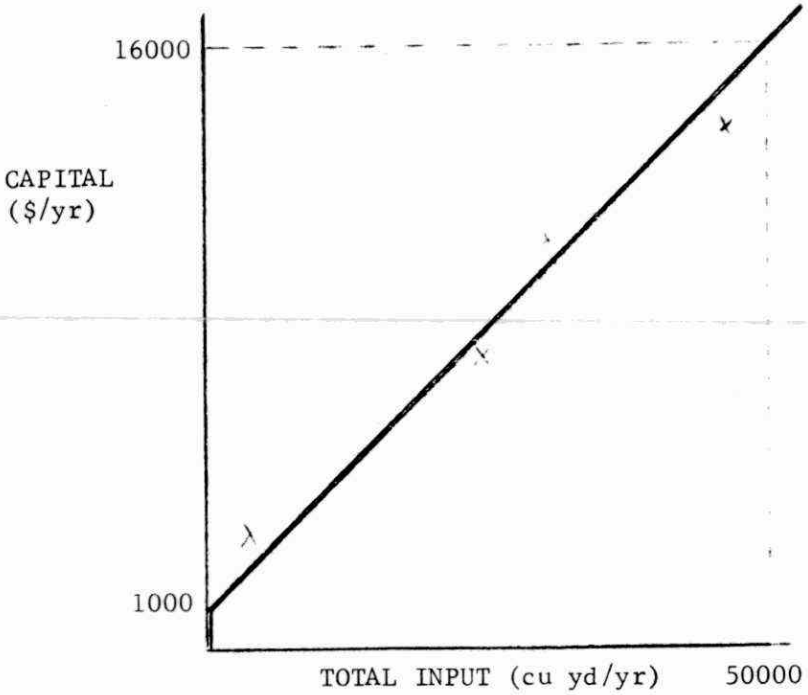
Recall that such a problem with size limit would not occur if all all-year dead-end facilities were not permitted to receive sludge directly from sources, as the program would then just omit all transport links between sources and these facilities.

Now you might consider the Cowtown vacuum filter. The existing facility still works and should be included in the model. But its current capacity, 40,000 cu yd/year, could possibly be profitably increased if it served sources other than Cowtown, or even if it just served Cowtown when the source output increased in the future. Thus, a potential facility representing an expanded Cowtown vacuum filter is introduced into the model. This is modelled separately from the existing facility, because its cost functions are so different from those of the existing facility. You include both the existing and the expanded facilities in the model, the

(a) O & M for Mogul Hill



(b) Capital for Soupy Hollow



(c) O & M for Soupy Hollow

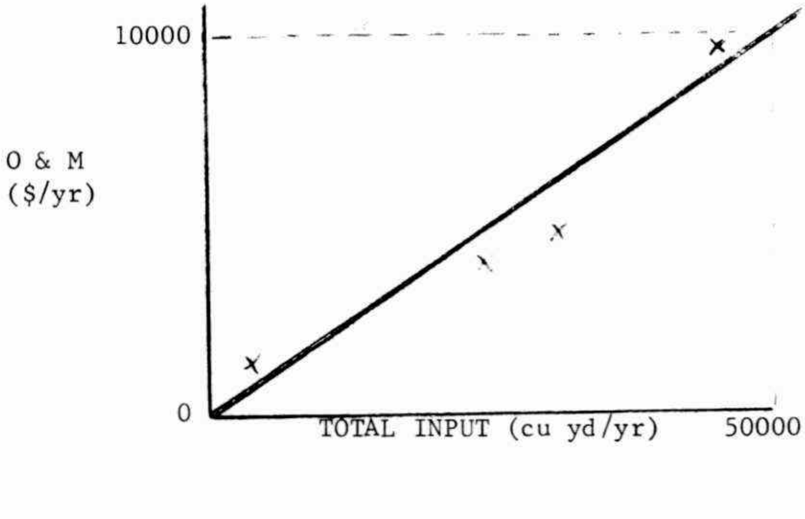


FIGURE 28. LANDFILL COST FUNCTIONS FOR SIMPLE EXAMPLE

size limit on the latter twice that on the former. The cost functions are as shown in Figure 26 in the preceding chapter.

Now, having introduced a potentially large dewatering facility into the model, suppose you think there is a possibility that a treatment facility which performs a large volume reduction service - i.e. a centralized service for several sludge sources - might be better located nearer the landfills and the other sources. You find that the most feasible site for such an alternative would be at the location of the potential landfill at Soupy Hollow. Since this is a sparsely populated area, the facility would incorporate an incinerator as well as a dryer. Due to the transport distance from the Cowtown plant, it would not likely serve much of the production from that source; but it could serve Pigden, Sheepville and Sewerpipe, while the surviving agricultural land spreading sites are mostly near Cowtown and could probably take care of a lot of its production. So you decide to put an all-year intermediate potential facility at Soupy Hollow, representing a combination dewatering-incineration plant. The cost function for this plant has no particular difficulties, although the capital cost is of course very high. Since the facility could obviously be economical only for high volumes, the cost function curve should be fitted to your calculated points with emphasis on accuracy at the higher values of total input.

There are just four sites where agricultural land spreading will be feasible in the next several years: Woodside and Greengarter, which are near Cowtown and can serve the village of Fencehole as well; Mudfoot, which is close to Sewerpipe; and Sticky Creek, which is a fair distance away from anything else. The soil conditions and the area available at each of these locations determines the limit on total annual input to each potential facility, and they all can be used for about seven months of the year. Their cost functions are peculiar in that they have no significant fixed charge; and the capital cost is zero since it does not appear necessary for the regional government to obtain ownership of the land and no special spreading equipment is being considered.

Adjacent to the land spreading site at Mudfoot there is a lagoon, badly in need of maintenance, used at the present as a winter holding tank by a sludge contractor who would probably be willing to sell all rights and responsibilities for it to you. Accordingly, you put the Mudfoot lagoon into the model. But its size limit is just equal to its present capacity since it is not feasible to expand the facility. In order to take good advantage of all four land spreading sites it would be necessary to have a new lagoon in an area where it could potentially have a very large size. There are just two feasible locations for such a new facility: Port Crystal and Bean Flats, both, unfortunately, on the opposite side of the region from the land spreading sites. Port Crystal has the advantage of being on a large river which could assimilate a supernatant stream out of a lagoon, so that as an intermediate facility it would have a larger volume reduction factor than at Bean Flats. On the other hand at Bean Flats, the advantage is the height of the plateau where it is situated, assuring no problems with groundwater or ventilation. So you put two winter intermediate potential facilities into the model, one at Port Crystal and one at Bean Flats. If the computer finds that it does not make much difference in dollars which one is used, and their use does lead to optimal or near-optimal solutions, you will choose Bean Flats over Port Crystal on environmental grounds.

The cost functions of the lagoons are not complicated, the main cost being capital for the land and initial excavation. Equipment for dredging the lagoons must also be included. For the Mudfoot lagoon, the capital cost has a high fixed charge and no variable cost, since for any total input over zero up to the present capacity the same thing would have to be bought.

Your model now contains twelve potential facilities classified by type as shown in Table 6. Suitable abbreviations are shown which we shall assume that you have chosen. It is a good idea now to collect the facility information together as shown in Table 7.

Your next job is to obtain and formulate cost information for sludge transport. This could be a very tedious job if it is not done systematically. There are 5 x 12 = 60 transport links from sources to facilities, 3 x 4 = 12 links from winter intermediate to all-year dead-end facilities, and 3 x 2 = 6 links from all-year intermediate to all-year dead-end facilities. All of these 60 + 12 + 6 = 78 transport links, illustrated in Figure 29 (which you would not usually need to draw), must have cost functions assigned to them.

TABLE 6. POTENTIAL FACILITIES IN SIMPLE EXAMPLE

Abbreviation	Facility	Category
BFHL	Bean Flats Holding Lagoon	winter intermediate
CVF1	Cowtown Vacuum Filter (existing)	all-year intermediate
CVF2	Cowtown Vacuum Filter (expanded)	all-year intermediate
GGLS	Greengarter Landspreading Site	summer dead-end
MHLF	Mogul Hill Landfill	all-year-dead-end
MFHL	Mudfoot Holding Lagoon	winter intermediate
MFLS	Mudfoot Landspreading Site	summer dead-end
PCHL	Port Crystal Holding Lagoon	winter intermediate
SHDI	Soupy Hollow Drier-Incinerator	all-year intermediate
SHLF	Soupy Hollow Landfill	all-year dead-end
SCLS	Sticky Creek Landspreading Site	summer dead-end
WSLS	Woodside Landspreading Site	summer dead-end

TABLE 7. FACILITY INFORMATION IN SIMPLE EXAMPLE

FACILITY	TYPE*	SIZE LIMIT	VOLUME REDUCTION FACTOR	CAPITAL COST		O & M COST	
				FIXED CHARGE	VARIABLE COST	FIXED CHARGE	VARIABLE COST
1. GGLS	DS	20,000**	-	0	0.0	0	0.1
2. WSLS	DS	20,000	-	0	0.0	0	0.1
3. SCLS	DS	50,000	-	0	0.0	0	0.1
4. MFLS	DS	30,000	-	0	0.0	0	0.1
5. CVF1	IA	40,000	0.25	3,000	0.0	20,000	1.3
6. CVF2	IA	80,000	0.25	20,000	1.5	30,000	1.0
7. SHD1	IA	100,000	0.15	85,000	1.1	60,000	0.6
8. SHLF	DA	50,000	-	1,000	0.3	0	0.2
9. MHLF	DA	1	-	0	0.0	0	0.1
10. MFHL	IW	40,000	0.9	50,000	0.0	300	0.2
11. PCHL	IW	0	0.8	1,000	1.3	0	0.2
12. BFHL	IW	0	0.7	1,000	1.3	0	0.2

* IA = all-year intermediate
IW = winter intermediate
DA = all-year dead-end
DS = summer dead-end

** cu yd /yr.

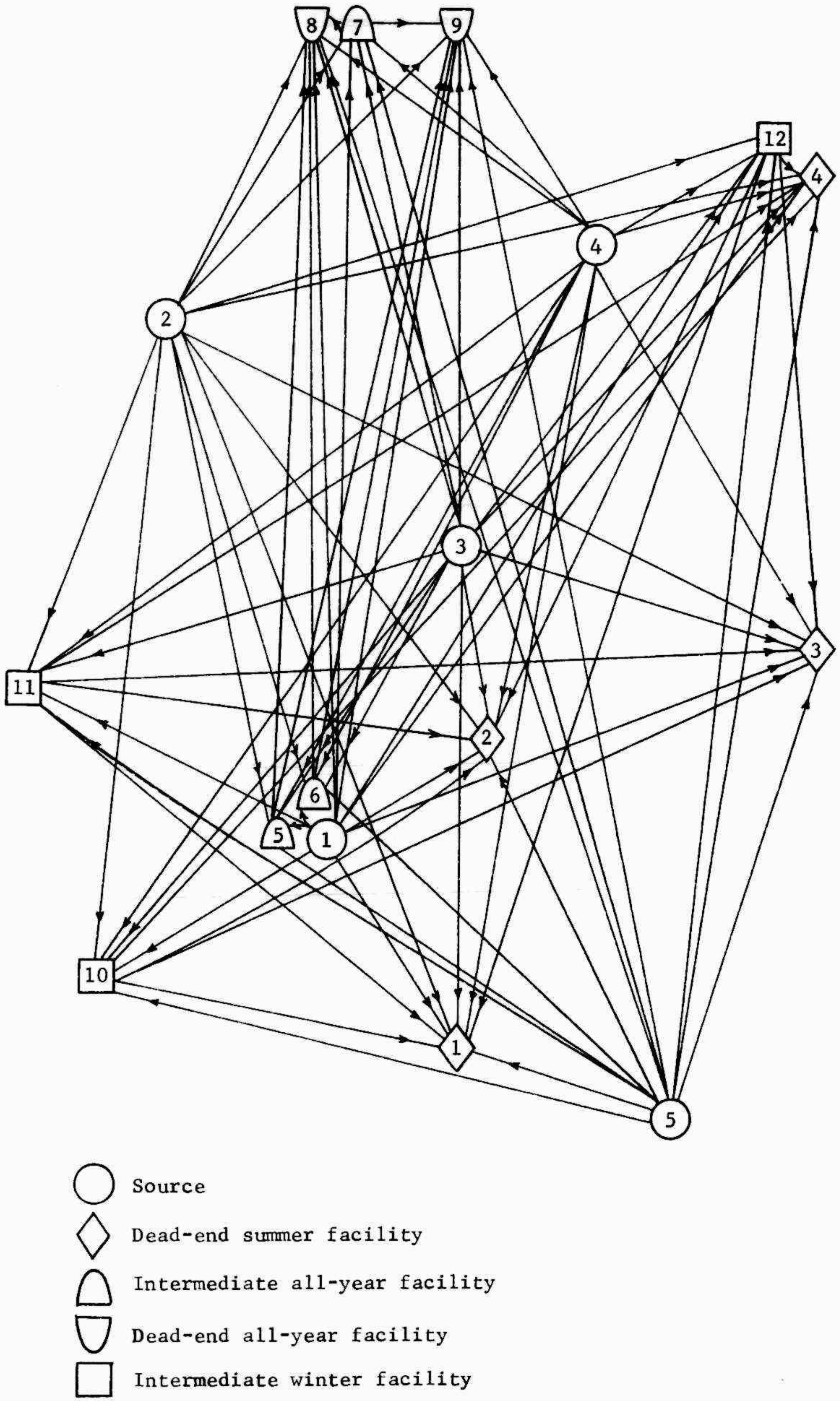

8
7
9
12
4
4
2
3
3
11
2
6
5
1
10
1
5
Source
Dead-end summer facility
Intermediate all-year facility
Dead-end all-year facility
Intermediate winter facility

FIGURE 29. SCHEMATIC ILLUSTRATION OF SOURCES AND POTENTIAL FACILITIES, SHOWING ALL TRANSPORT LINKS

The best way to start is to set up tables, such as those in Table 8, for each type of transport link. Each element in the tables represents one link. The tables you work with should be spacious enough to contain small notes and scratch pad calculations. The tables have the same arrangement of numbers as that required by the answer tables in the questionnaire in Appendix IV.

Each element in Table 8 contains two numbers: a haulage formula indicator and, below this, a trip length. We shall now discuss a process by which you might obtain these numbers shown in this example.

First, you have to decide whether you want to use the straightforward approach of estimating the transport cost per cubic yard for each transport link without telling the program about any haulage formulas. This would be advantageous if you had a large quantity of data that would make it quite easy to obtain this cost function slope for every transport link. But if your estimates are going to contain much uncertainty, you may want to use haulage formulas anyway to keep your estimates consistent and your calculations systematic; in that case, you may as well give the haulage formulas to the program and let it do the calculations, thus saving you a lot of work. Moreover, if your estimates are uncertain you will probably want to run the program with variations in the estimates: then it is much easier to change a few haulage formulas than to recalculate a large number of transport link cost functions.

Suppose, for the sake of example, that good information on recent haulage costs is available only in the form of total cost and quantity of each contract let to two different contractors in the region. One contractor always takes care of haulage from Cowtown and Fencehole, while the other takes care of haulage from Pigden, Sheepville and Sewerpipe; this second contractor also has cornered all haulage concerned with the Mudfoot lagooning and land spreading facilities. There is no reason to think this situation will change in the near future, so transport cost functions should represent the prices charged by these contractors.

Suppose further that the Cowtown/Fencehole contractor is able and willing to give you detailed information on some of his operations that you can use as a basis for your cost functions. From this information you can estimate a breakdown of cost and quantity of past contracts

TABLE 8. FORMULATION OF TRANSPORT COST INFORMATION

	From Sources				
To Facilities	1	2	3	4	5
1	1 40	5 60	5 50	5 55	1 25
2	1 30	5 50	5 30	5 45	1 30
3	1 60	5 60	5 35	5 40	1 30
4	5 80	5 50	5 50	5 20	2 0
5	3 0.01	7 60	7 40	7 60	6 45
6	3 0.01	7 60	7 40	7 60	6 45
7	6 55	7 30	7 50	7 30	2 0
8	6 55	7 30	7 50	7 30	2 0
9	2 0	2 0	2 0	2 0	2 0
10	6 40	7 50	7 50	7 55	6 35
11	6 45	7 35	7 45	7 50	6 50
12	7 80	7 50	7 50	7 20	2 0

	From Winter Intermediate Facilities		
To Summer Dead-end Facilities	10	11	12
1	1 30	1 50	2 0
2	1 40	1 45	5 45
3	1 50	1 55	5 30
4	5 80	5 65	3 0.01

	From All-year Intermediate Facilities		
To All-year Dead-end Facilities	5	6	7
8	4 55	4 55	3 0.02
9	4 50	4 50	4 15

Haulage Formulas:

(1) $1.30 + 0.04d$
(2) $20.0 + 0.00d$
(3) $0.00 + 1.00d$
(4) $1.00 + 0.06d$
(5) $1.56 + 0.048d$
(6) $1.17 + 0.04d$
(7) $1.40 + 0.048d$

yielding a separate cost per cubic yard for haulage to Greengarter, Woodside and Sticky Creek, respectively, from Cowtown. These are the slopes (unit costs) for the cost functions for these three transport links. If all the links were this easy you might not want to worry about haulage formulas; however, there are 75 links to go which have no quantitative information.

As explained in the preceding chapter, a haulage formula gives the slope of a transport link cost function as "a + bd", where "a" and "b" are characteristic of the haulage formula and "d" is characteristic of the transport link. Usually, one haulage formula can be used for several transport links. Different haulage formulas would be expected to apply to different haulage contractors and to different types of transport links. The coefficient "a" represents overhead as well as labour for loading and unloading. The coefficient "b" represents the contribution to unit cost per unit of the transport link characteristic "d", which represents the trip length for the transport link.

You would expect the three links from Cowtown to Greengarter, Woodside and Sticky Creek, respectively, to have the same haulage formula. As well as a breakdown of cost and quantity among these links, an estimate of the travelling distance or time required on each link for one haul can be obtained. This gives you a trip length or value of "d" which is characteristic for each link*. Suppose your numbers are as shown in Table 9. Now, plotting cost per cubic yard versus trip length and fitting a straight line to the three points, you find that the unit cost can be estimated fairly well by the haulage formula 1.30 + 0.04d. This gives unit costs of 2.90, 2.50 and 3.70, comparing well with the observed numbers 3.00, 2.50, and 3.40. A perfect fit need not be obtained since the observed numbers are really only characteristic estimates. You might also wish to give observed points involving larger quantities greater weight in the line fitting since the price on their contracts is probably more consistent and possibly the information on quantity, cost and trip length is more accurate.

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* You could also use travelling time or distance required for five hauls, or for transporting 1000 cu yd between the two points, or any other standard measure you wish to set.

TABLE 9. EXAMPLE OF DATA ESTIMATED FROM PAST CONTRACTS IN ORDER TO OBTAIN A HAULAGE FORMULA

From Source Number 1 to Facility	Quantity	($) Cost	Unit Cost ($/cu yd)	Trip Length "d" (Minutes)
1	7000	21,000	3.00	40
2	8000	20,000	2.50	30
3	5000	17,000	3.40	60

Now you have haulage formula number 1 with a = 1.30 and b = 0.04. You could assume this applies to the links from the Bean Flats and Port Crystal lagoons, as well as from Cowtown and Fencehole, to the land spreading sites at Greengarter, Woodside and Sticky Creek. This yields all the entries of the number "1" in Table 8.

The accompanying trip lengths for these links are estimated from a road map wherever they are not available from the haulage contractors. If the region had a dense road system and traffic conditions were uniform, you could avoid the work of entering all the trip lengths by giving the program (x,y) coordinates of all the sources and facilities, instructing the program to estimate trip lengths by calculating the straight-line distance and multiplying by a correction factor that you provide. However, this approach is not used in this example.

Next, you might consider a special haulage formula that would give certain links a prohibitively high unit cost, for instance with a = 20 and b = 0. This formula, number 2, is used for all links directly from sources to the Mogul Hill landfill, as you have decided previously that these transport links should be removed from the model. This formula yields a unit cost that appears prohibitive but is not an order of magnitude larger than unit costs on other links. It is not made larger than necessary because the program will scale the numbers for computation on the basis of the largest number in each type of data.

Haulage formula number 2 is also useful for ruling out links that are clearly impractical for reasons of very long trip length combined with small quantities, or political reasons. Thus, you decide to use formula 2 for the links from Fencehole to Soupy Hollow and Mudfoot, and from Mudfoot to Woodside. This yields all the remaining entries of the number "2" in Table 8. For any link using formula 2, the trip length can be entered as any arbitrary number (eg. zero) since $b = 0$.

Another special haulage formula you wish to use has $a = 0$ and $b = 1$. This allows you to enter unit costs directly, disguised as trip length. In this example, the only place you want to do this is on links where the actual trip length is insignificant so that real haulage formulas would not make any sense*, namely on the links from Cowtown source to Cowtown vacuum filters (existing and expanded), from Mudfoot lagoon to Mudfoot land spreading site and from Soupy Hollow dryer-incinerator to Soupy Hollow landfill. The method of transport is probably pipeline for all of these links except the last, which is probably a conveyor. In any case, you would guess that the unit cost on these links is very small and need not be accurately estimated. This yields the entries of the haulage formula indicators "3" and the accompanying fractional "trip lengths" in Table 8.

For haulage of ash from the dryer-incinerator to Mogul Hill, and of dewatered sludge from the Cowtown vacuum filters, a fourth haulage formula is needed that is valid for hauling of solid materials in open trucks. This is estimated from recent experience with the existing Cowtown vacuum filter as a formula with $a = 1$ and $b = 0.06$. Compared to formula 1, the overhead part is lower due to the more inexpensive type of truck, but the trip length dependent part is higher due to the higher density of the material.

Consider now the contractor who will haul from Cowtown to the Mudfoot land spreading site and from Pigden, Sheepville and Sewerpipe to Mudfoot and all other land spreading sites. You may not have much precise information to work with, but from past experience you may know that the overall unit cost is larger than with the other contractor, possibly because of smaller sized trucks. So you simply use a formula with "a" and "b" about 20% larger than in formula 1. This formula, number 5, is probably also valid for the transport links between the Mudfoot facilities and the lagoons at Bean Flats and Port Crystal.

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* In general, you might want to do this on any link where the use of a real haulage formula would have no advantage.

For transport links from the sources to all facilities other than land spreading sites, the same haulage formulas would probably apply, but with reduced values of "a" due to smaller unloading cost. Thus, you have formulas 6 and 7, which are the same as 1 and 5 with 10% smaller values of "a".

Now you are finished with the transport links. You have seven haulage formulas and Table 8 is complete. You will feel that the transport cost estimates are very rough, but this is typically the best you can do. You will study the effect of the uncertainty of the estimates by running the program two or three times with variations in the haulage formulas - for example with formula 5 made larger or smaller relative to formula 1, or with all formulas except 2 and 3 increased 30% to see the effect of an overall increase in haulage costs relative to facility costs. When you see the optimal solutions obtained by the program, you can add up the transport link hauls assigned to each contractor and see if the total costs predicted are reasonably close to the prices the contractors would probably charge.

Having finished assembling the model, you can look at the additional details required to make a computer run.

First, MAXSOL, the total number of solutions you are interested in, including near-optimal solutions as well as the optimal solutions, is probably quite high, say 15. In addition, you specify EPS, the range of annual total system costs you are interested in, say $50,000. If the solutions in this range over the optimal solution are not all included in the 15 you ask for, the program will tell you.

Next, you decide the fraction of the year during which the summer dead-end facilities cannot be used as 5/12 = 0.417. As an initial trial you set the weight factor, for biasing the winter optimization, at zero (i.e. no bias).

Intending to make a complete run, allowing the program to consider all possible facility combinations, you remark that the number of combinations evaluated will be roughly $2^{(12 - 5)} = 128$ since there are 12 facilities of which 5 have zero fixed charge*. You specify that these facilities with zero fixed charge are to be included in every combination evaluated. The two Cowtown vacuum filters (existing and expanded) certainly could not both be used simultaneously; so you specify that this pair (facilities 5 and 6) should not occur in any combination evaluated. This will make the number of combinations evaluated significantly smaller than 128.

You would like to see printouts of several solutions during the optimization process to see what the program is doing; so you specify that such printouts should be made for every 10th facility combination evaluated. So ARBOUT is 10. Since the program will run in a very short time, you do not expect to need any data dumps; so you specify that a data dump should occur only after every 1000th facility combination evaluated. So IDUMP is 1000.

Since you have no idea what typical total costs of the optimal or near-optimal solutions will be, you will just leave this item blank when you answer the questionnaire to set up the data deck for the run.

This is all that is required to make a run.

7.2 Niagara Study

7.2.1 Problem description

Sludge disposal in the Regional Municipality of Niagara is described in general terms in Chapter 2. Here we shall summarize the points that are important for our model.

A simplified map of the region, with pertinent features, is shown in Figure 30. Vacuum filter facilities exist at Port Dalhousie, Niagara Falls and Welland, although they are not used at the present time. The two largest sludge sources are Port Weller and Port Dalhousie, which are very close together. Their combined production is expected to triple

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* This is an atypically small number of combinations for evaluation; in reality, it is usually much larger, as seen later in the discussion of the Niagara study.

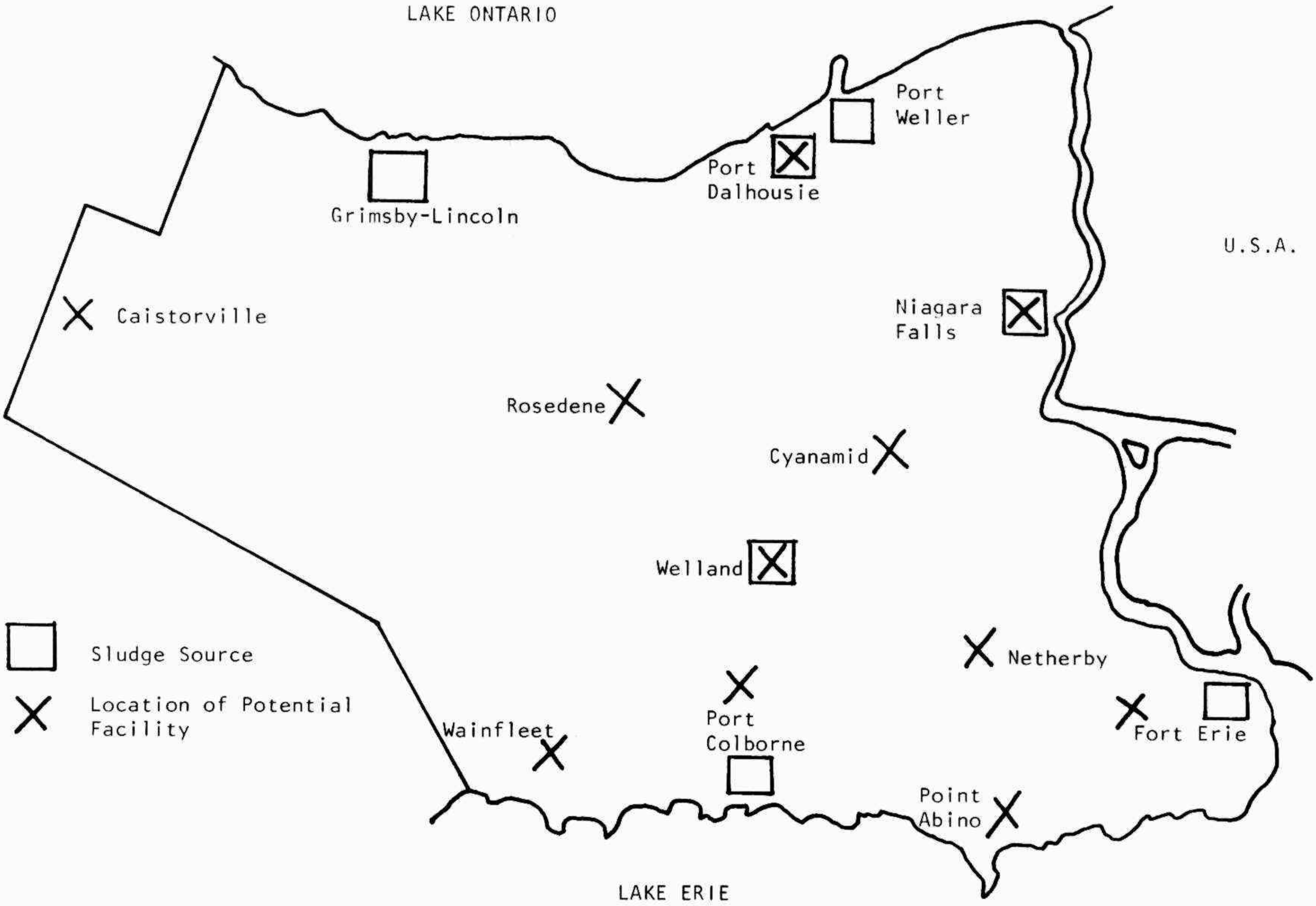

FIGURE 30. MAP OF REGION FOR THE NIAGARA STUDY

in the next ten years. The next largest source is Niagara Falls, which is expected to quadruple in the next ten years, as are the smaller sources at Fort Erie and Port Colborne. Grimsby-Lincoln is a name representing three very small plants which are soon to be replaced by one modern plant. The production from this source, like that from Welland, is expected to grow by a factor of ten in the next ten years. The predictions furnished by the Regional Municipality are shown in Table 10.

The present sludge disposal system consists primarily of land application with some dewatering operations using drying lagoons and windrowing. It is possible in the future to have any of three alternative treatment components: holding tank, land spreading, or drying lagoon facilities, at any of eight locations: Netherby, Point Abino, Cyanamid, Rosedene, Wainfleet and Caistorville, and almost on-site at the Fort Erie and Port Colborne sources. The land spreading sites could only be used during one-half of the year.

TABLE 10. SLUDGE PRODUCTION AT SOURCES (THOUSANDS OF GALLONS)

	Source	1974	1980	1990
1.	Grimsby-Lincoln	332	5400	6900
2.	Port Weller	5817	19770	24525
	Port Dalhousie	2597		
3.	Niagara Falls	2448	11400	14250
4.	Fort Erie	184	4155	4995
5.	Port Colborne	894	3210	4425
6.	Welland	800	7965	9720
	Totals	13072	51900	64815

These 24 alternatives, plus the three existing vacuum filters, are the potential facilities for use in a future sludge disposal system. It is desired initially to consider all possible transport links between the facility types as shown in Figure 31. The dewatering facilities (drying lagoons and vacuum filters) are assumed to have storage capacity for retaining sludge dewatered in "winter", until "summer" when it can be applied to the land. For purposes of the study it was decided that the current practice of windrowing dewatered sludge and storing it for private citizens to pick up could not be counted on to handle the whole output that the dewatering facilities might produce in the future; so this method of ultimate disposal was ignored. Some of the source output sent to these dewatering facilities in the "winter", along with the source output sent to holding tanks, can be diverted to the land spreading sites in "summer", thus allowing the option of sending some holding tank inventory (accumulated in "winter") through the dewatering facilities in "summer".

7.2.2 The model

The desire to consider sending sludge from holding tanks to dewatering facilities and from dewatering facilities to land spreading sites complicates the problem of formulating a model. In this manual, just one of the models used in the Niagara study is presented.

First of all, the possibility of transport from holding tanks to dewatering (vacuum filter and drying lagoon) facilities was ruled out so as to avoid any 3-link paths "from source to holding tank to dewatering facility to land spreading". It seems highly unlikely that any such paths would be included in an optimal or near-optimal solution. This is because any sludge sent on such a path could probably be handled more cheaply by sending it directly from the source to the dewatering facility. Furthermore, it is impossible to explicitly model 3-link paths for the ALLO2 computer program.

If a dewatering facility is not used at the same rate in both winter and summer, it must be oversized. This cannot be an economically justified use, so the most practical situation is for the distribution between the sources and the dewatering facility to be constant all year. Then the dewatering facilities are all-year facilities in terms of the model required by the program, while the holding tanks and land spreading sites can be called winter intermediate and summer dead-end facilities, respectively.

The question then is what to do with the transport possibilities considered between the dewatering facilities and the land spreading sites. The program ALLO2 does not accept transport links from all-year to summer facilities. This difficulty was handled by increasing the O & M variable cost of each dewatering facility by an assumed cost of ultimate disposal, and modelling the facility as an all-year dead-end facility. For each

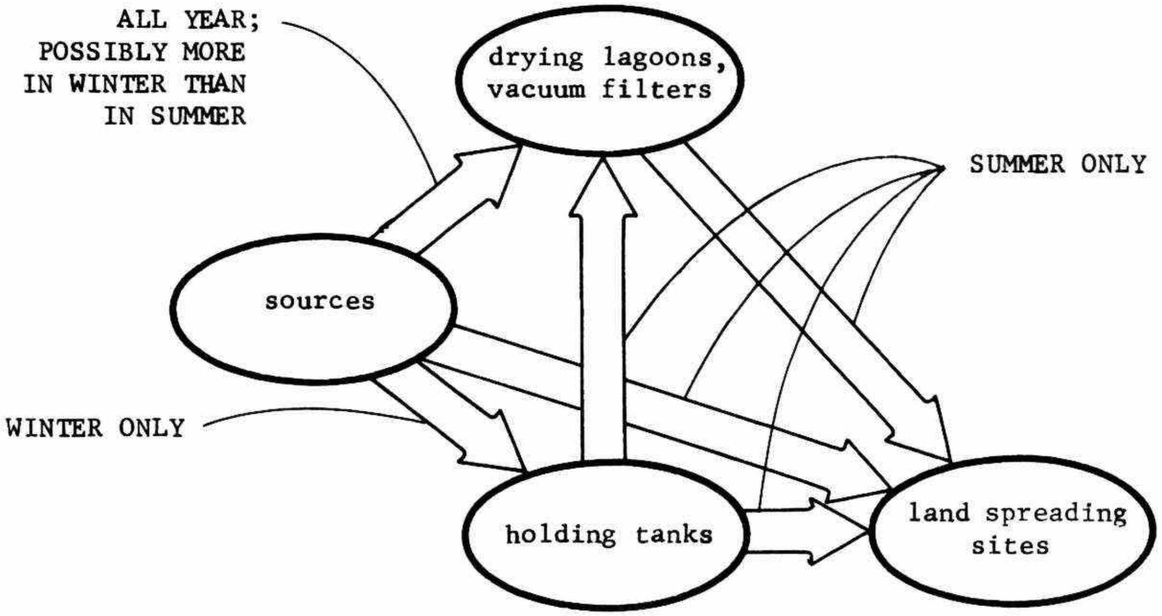

FIGURE 31. TYPES OF TRANSPORT IT IS INITIALLY DESIRED TO CONSIDER

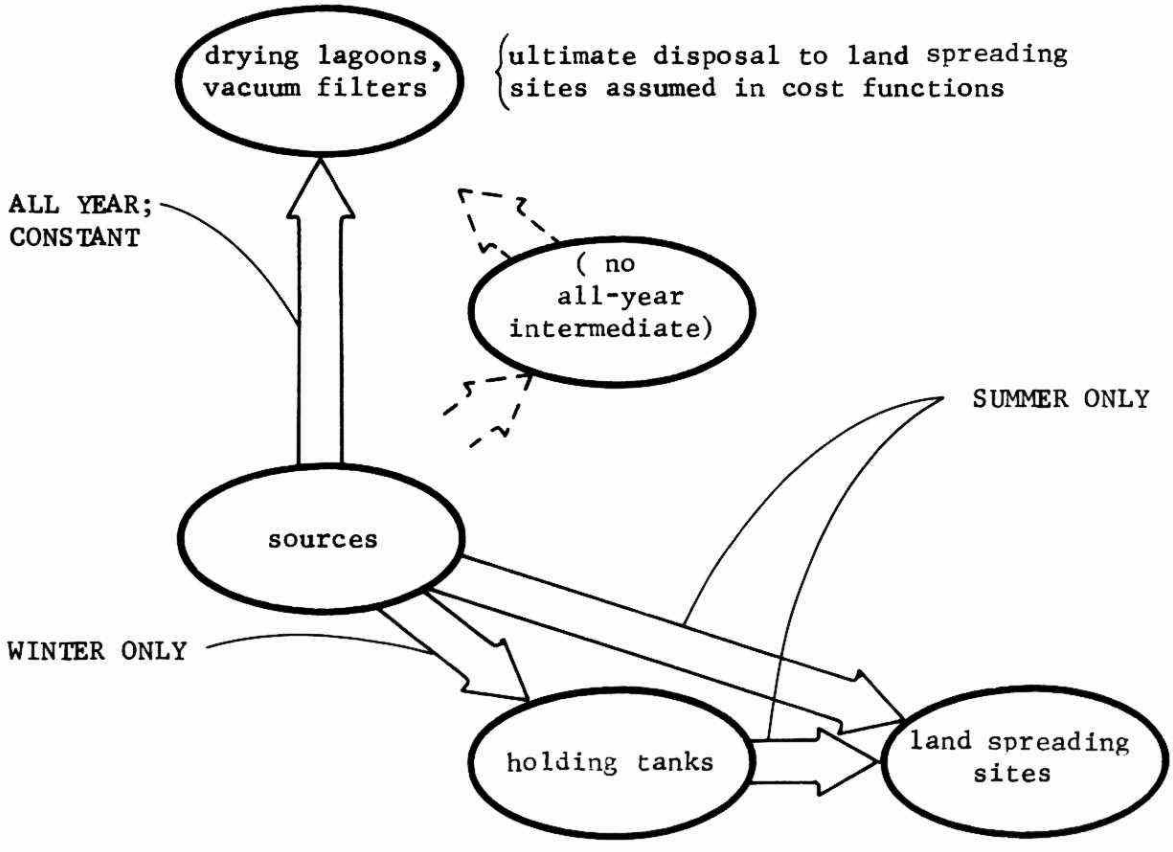

FIGURE 32. MODIFICATION OF FIGURE 31 TO OBTAIN A MODEL FOR ALLO2

of these facilities, the assumed cost of ultimate disposal was obtained as its volume reduction factor times the lowest value of (B + C) observed on any link from the facility to a land spreading site*. This, in effect, assigned a particular land spreading site to each dewatering facility in a way that ignored each site's limit on total input. It was expected that this would not invalidate any optimal or near-optimal solutions and it was found that the solutions were satisfactory in this respect.

The form of the model is pictured schematically in Figure 32. It has the same shape as the general model accepted by the program except that there are no all-year intermediate facilities.

The information on the potential facilities is listed in Table 11. The size limits on the vacuum filters were equal to their current capacity. The variable O & M cost of the all-year dead-end facilities, including the cost of ultimate disposal determined, is shown in Table 12. In Table 12 some of the abbreviations used for facility names are shown. Part (a) of Table 12 shows the values of C calculated to find the cheapest ultimate disposal destination for each of the facilities, while part (b) shows the calculation with the chosen destination. It can be seen that these calculations were not difficult since they involved much repetition. Even part (a) is not as bad as it looks. The same haulage formula, "0.004 + 0.006 times trip length in hours" was used for all links except the eight links which join facilities at the same location. In the latter case, the formula "0.000072 times trip length in miles" was used. Furthermore, the first eight rows in part (a) form a matrix which is symmetric about the diagonal since the trip length (one haul, return trip) between two points was assumed to be independent of direction: thus, only half of this matrix had to be calculated, then the other half was known.

The haulage formula with a=0.004 and b=0.006 was obtained as follows. A 5000-gallon truck was assumed rented at a cost of $30/hour, including driver wages. Loading and unloading time was assumed to be two-thirds of an hour. The cost per gallon transported was then:

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* As explained in Chapter 5, (B + C) is the unit variable cost of distribution: C is the slope of the transport link cost function and B is the variable cost (capital plus O & M) of the facility at the end of the link.

TABLE 11. FACILITY INFORMATION IN NIAGARA CASE STUDY

				CAPITAL COST		O & M COST	
FACILITY	TYPE	SIZE LIMIT*	VOLUME REDUCTION FACTOR	FIXED CHARGE	VARIABLE COST**	FIXED CHARGE	VARIABLE COST**
1. Fort Erie Land spread	DS	1500	-	0	0.0	0	0.0
2. Netherby Land spread	DS	20000	-	0	0.0035	0	0.0015
3. Port Colborne Land spread	DS	2150	-	0	0.0	0	0.0
4. Point Abino Land spread	DS	20000	-	0	0.0035	0	0.0015
5. Cyanamid Land spread	DS	20000	-	0	0.0035	0	0.0015
6. Rosedene Land spread	DS	20000	-	0	0.0035	0	0.0015
7. Wainfleet Land spread	DS	20000	-	0	0.0035	0	0.0015
8. Caistorville Land spread	DS	20000	-	0	0.0035	0	0.0015
9. Fort Erie Drying Lagoon	DA	2580	-	0	0.0052222	0	0.00000468
10. Netherby Drying Lagoon	DA	9000	-	0	0.013	0	0.00280468
11. Port Colborne Drying Lagoon	DA	3580	-	0	0.0052222	0	0.00000468
12. Point Abino Drying Lagoon	DA	9000	-	0	0.013	0	0.00280468
13. Cyanamid Drying Lagoon	DA	9000	-	0	0.013	0	0.00280468
14. Rosedene Drying Lagoon	DA	9000	-	0	0.013	0	0.00280468
15. Wainfleet Drying Lagoon	DA	9000	-	0	0.013	0	0.00280468
16. Caistorville Drying Lagoon	DA	9000	-	0	0.013	0	0.00280468
17. Pt. Dalhousie Vacuum Filter	DA	5900	-	3000	0.0	35000	0.010322
18. Niagara Falls Vacuum Filter	DA	2450	-	3000	0.0	35000	0.0177288
19. Welland Vacuum Filter	DA	1800	-	3000	0.0	35000	0.0261448
20. Fort Erie Holding Tank	IW	27000	1.0	3000	0.0013991	200	0.0000074
21. Netherby Holding Tank	IW	27000	1.0	3000	0.0023045	200	0.0000074
22. Pt. Colborne Holding Tank	IW	27000	1.0	3000	0.0013991	200	0.0000074
23. Pt. Abino Holding Tank	IW	27000	1.0	3000	0.0023045	200	0.0000074
24. Cyanamid Holding Tank	IW	27000	1.0	3000	0.0023045	200	0.0000074
25. Rosedene Holding Tank	IW	27000	1.0	3000	0.0023045	200	0.0000074
26. Wainfleet Holding Tank	IW	27000	1.0	3000	0.0023045	200	0.0000074
27. Caistorville Holding Tank	IW	27000	1.0	3000	0.0023045	200	0.0000074

* thousands of gallons
** dollars per gallon

TABLE 12. DETERMINATION OF ULTIMATE DISPOSAL COST FOR ALL-YEAR DEAD-END FACILITIES

FROM	TO	1 FELS	2 NELS	3 PCLS	4 PALS	5 CYLS	6 RSLS	7 WFLS	8 CSLS
9. FEDL		.000018	.0084	.012	.0088	.0112	.0145	.0132	.0187
10. NEDL		.0084	.000018	.0112	.0082	.0088	.014	.0132	.0204
11. PCDL		.012	.0112	.000018	.0096	.0106	.0116	.0072	.0164
12. PADL		.0088	.0082	.0096	.000018	.01	.0156	.0148	.0194
13. CYDL		.0112	.0088	.0106	.01	.000018	.0124	.0128	.016
14. RSDL		.0145	.014	.0116	.0156	.0124	.000018	.0096	.0116
15. WFDL		.0132	.0132	.0072	.0148	.0128	.0096	.000018	.0136
16. CSDL		.0187	.0204	.0164	.0194	.016	.0116	.0136	.000018
17. PDVF		.0124	.0128	.0144	.0156	.0128	.0128	.0144	.0196
18. NFVF		.0094	.0112	.0140	.016	.0088	.0128	.0144	.0196
19. WDVF		.0120	.008	.007	.0112	.0072	.0108	.0096	.0176

(a) Transport Link Unit Costs ($/Gal.)

FACILITY	VOLUME REDUCTION FACTOR	ULTIMATE DISPOSAL DESTINATION	B_1	B_2	C	B+C	INCREASE IN O & M VARIABLE COST ($/Gal.)
9. FEDL	0.26	1. FELS	0.0	0.0	0.000018	0.000018	0.00000468
10. NEDL	0.26	2. NELS	0.0035	0.0015	0.000018	0.005018	0.00130468
11. PCDL	0.26	3. PCLS	0.0	0.0	0.000018	0.000018	0.00000468
12. PADL	0.26	4. PALS	0.0035	0.0015	0.000018	0.005018	0.00130468
13. CYDL	0.26	5. CYLS	0.0035	0.0015	0.000018	0.005018	0.00130468
14. RSDL	0.26	6. RSLS	0.0035	0.0015	0.000018	0.005018	0.00130468
15. WFDL	0.26	7. WFLS	0.0035	0.0015	0.000018	0.005018	0.00130468
16. CSDL	0.26	8. CSLS	0.0035	0.0015	0.000018	0.005018	0.00130468
17. PDVF	0.19	1. FELS	0.0	0.0	0.0124	0.0124	0.002356
18. NFVF	0.19	5. CYLS	0.0035	0.0015	0.0088	0.0138	0.002622
19. WDVF	0.19	3. PCLS	0.0	0.0	0.007	0.007	0.00133

(b) Calculation of Increase in O & M Variable Cost due to Ultimate Disposal

$$C = (\$30/\text{hr}) \times (2/3\ \text{hr} + \text{trip length in hours}) \ / \ 5000\ \text{gal}$$

$$= \frac{\$30 \times 2}{3 \times 5000\ \text{gal}} + \frac{\$30}{5000\ \text{gal}} \times \text{trip length}$$

$$= \$0.004/\text{gal} + \$0.006\ \text{gal} \quad \times \text{trip length}$$

This is haulage formula number one. It applies to all transport links in the model which join points at different locations except for the link from the Welland source to the Netherby drying lagoon. For this link, a formula with a=0 and b=1 is used so that C can be entered directly. This is formula number three, after number two. Haulage formula number two has a=0 and b=0.000072 and is used for links between facilities which are virtually at the same location*. This formula's small value of "b" arises from rough estimates of the cost of power for a pump or conveyor whose other costs are assimilated into the cost of the facility**. The three links from sources to on-site vacuum filters do not have the same relationship, so they use formula number three which permits C to enter directly.

Table 13 shows the haulage formula indicator and trip length for every transport link from the sources to the facilities, while Table 14 shows this information for the links from holding tanks to land spreading sites. Since Port Weller and Port Dalhousie are so close together, they are combined and treated as one source. In these tables, all the abbreviations used for names of facilities and sources are shown.

For links with haulage formula number one, the trip lengths are shown in these tables in the form "hours:minutes", that is, before conversion of the minutes portion to a decimal fraction of an hour as the haulage formula requires***. It will be noted that almost every trip length is an even number of minutes, resulting from the estimation of

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* "Virtually" is used because, in reality, for instance, a holding tank may be several hundred yards away from a spreading field that is considered to be at the same location.

** Actually, it would have been better to include capital and maintenance costs in the coefficient "b" since they increase with the distance; but the distance was assumed the same whenever this formula was used anway.

*** It actually would have been easier in this case to use a haulage formula that requires trip lengths in minutes rather than hours, since it is easier to convert the hours to minutes than the minutes to hours.

TABLE 13. HAULAGE FORMULA INDICATORS AND TRIP LENGTHS FOR TRANSPORT LINKS FROM SOURCES TO FACILITIES

To Facility	From Source					
	1 GMLN	2 PWDH	3 NFLS	4 FERI	5 PCBN	6 WLND
1 FELS	1 2:06	1 1:24	1 0:54	1 0:16	1 1:20	1 1:20
2 NELS	1 1:45	1 1:30	1 1:12	1 0:52	1 0:56	1 0:40
3 PCLS	1 1:57	1 1:46	1 1:40	1 1:44	1 0:24	1 0:30
4 PALS	1 2:06	1 1:58	1 2:00	1 1:24	1 0:40	1 1:12
5 CYLS	1 1:42	1 1:26	1 0:48	1 1:28	1 1:12	1 0:32
6 RSLS	1 0:48	1 1:30	1 1:28	1 1:57	1 1:32	1 1:08
7 WFLS	1 2:00	1 1:48	1 1:44	1 1:56	1 0:32	1 0:56
8 CSLS	1 1:28	1 2:38	1 2:36	1 2:48	1 2:40	1 2:16
9 FEDL	1 2:06	1 1:24	1 0:54	1 0:16	1 1:20	1 1:20
10 NEDL	1 1:45	1 1:30	1 1:12	1 0:52	1 0:56	3 0.0008
11 PCDL	1 1:57	1 1:46	1 1:40	1 1:44	1 0:24	1 0:30
12 PADL	1 2:06	1 1:58	1 2:00	1 1:24	1 0:40	1 1:12
13 CYDL	1 1:42	1 1:26	1 0:48	1 1:28	1 1:12	1 0:32
14 RSDL	1 0:48	1 1:30	1 1.28	1 1:57	1 1:32	1 1:08
15 WFDL	1 2:00	1 1:48	1 1:44	1 1:56	1 0:32	1 0:56
16 CSDL	1 1:28	1 2:38	1 2:36	1 2:48	1 2:40	1 2:16
17 PDVF	1 1:08	3 0.003	1 1:00	1 1:42	1 1:36	1 1:16
18 NFVF	1 1:52	1 1:04	3 0.0	1 1:15	1 1:36	1 1:04
19 WDVF	1 1:39	1 1:20	1 1:04	1 1:28	1 0:36	3 0.0
20 FEHT	1 2:06	1 1:24	1 0:54	1 0:16	1 1:20	1 1:20
21 NEHT	1 1:45	1 1:30	1 1:12	1 0:52	1 0:56	1 0:40
22 PCHT	1 1:57	1 1:46	1 1:40	1 1:44	1 0:24	1 0:30
23 PAHT	1 2:06	1 1:58	1 2:00	1 1:24	1 0:40	1 1:12
24 CYHT	1 1:42	1 1:26	1 0:48	1 1:28	1 1:12	1 0:32
25 RSHT	1 0:48	1 1:30	1 1:28	1 1:57	1 1:32	1 1:08
26 WFHT	1 2:00	1 1:48	1 1:44	1 1:56	1 0:32	1 0:56
27 CSHT	1 1:28	1 2:38	1 2:36	1 2:48	1 2:40	1 2:16

NOTE: For links with haulage formula number one, trip lengths are shown in the form "hours:minutes".

TABLE 14. HAULAGE FORMULA INDICATORS AND TRIP LENGTHS FOR TRANSPORT LINKS FROM HOLDING TANKS TO LAND SPREADS

	From Facility							
To Facility	20 FEHT	21 NEHT	22 PCHT	23 PAHT	24 CYHT	25 RSHT	26 WFHT	27 CSHT
1 FELS	2 0.25	1 0:44	1 1:20	1 0:48	1 1:12	1 1:45	1 1:32	1 2:27
2 NELS	1 0:44	2 0.25	1 1:12	1 0:42	1 0:48	1 1:40	1 1:32	1 2:44
3 PCLS	1 1:20	1 1:12	2 0.25	1 0:56	1 1:06	1 1:16	1 0:32	1 2:04
4 PALS	1 0:48	1 0:42	1 0:56	2 0.25	1 1:00	1 1:56	1 1:48	1 2:34
5 CYLS	1 1:12	1 0:48	1 1:06	1 1:00	2 0.25	1 1:24	1 1:28	1 2:00
6 RSLS	1 1:45	1 1:40	1 1:16	1 1:56	1 1:24	2 0.25	1 0:56	1 1:16
7 WFLS	1 1:32	1 1:32	1 0:32	1 1:48	1 1:28	1 0:56	2 0.25	1 1:36
8 CSLS	1 2:27	1 2:44	1 2:04	1 2:34	1 2:00	1 1:16	1 1:36	2 0.25

NOTE: For links with formula number one, trip lengths are shown in the form "hours:minutes".

one-way travel time to the nearest minute and doubling the estimate to obtain return trip length.

Table 13 is not as complicated as it looks since the data for facilities 20 through 27 are the same as the data for the facilities 1 through 8, respectively, and except for one transport link, the data are the same for facilities 9 through 16, respectively. Table 14 is also easily constructed since it is a diagonally symmetric matrix.

This completes the discussion of the model with its "normal" cost functions, that is, the cost functions thought to be the most likely correct.

7.2.3 Computer runs made; data modifications

The information presented here is sufficient for three cases of data since source output are given for three different points in time. These cases were all run.

Cases were also run with two modifications. In the first modification, haulage formula number one's coefficient "a" (representing loading and unloading time) was increased 50%; also the vacuum filter size limits were raised 50% by 1980 and 100% by 1990. The vacuum filter cost functions were not changed, however, to reflect the potential cost of expansion*. In the second modification, both coefficients of haulage formula number one (thus representing truck rental and driver wage rates), as well as the facility O & M coefficients (largely representing power and labour), were raised by 20% by 1980 and 60% by 1990.

The facility capital cost coefficients were kept the same in every case, i.e., no matter which time period was being run (1974, 1980 or 1990). It was assumed that the planning decisions were being made with the same facilities existing in the previous period as those that exist now. This means that the solutions obtained for 1980 and 1990 contain overestimated capital costs for facilities that would exist by then according to the solutions obtained for 1974 and 1980, respectively. However, this is a first approximation which could be improved with further runs if necessary.

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* Thus, an indication was obtained regarding the desirability of expansion without taking capital cost into account.

The computer runs made for this study are listed in Table 15. The table shows that for each data modification and year, before a complete survey run was made, three short runs with one specified facility combination were made to test the value of the weight factor. These short runs were also valuable for checking out the input data for the model. Each complete survey was made with a weight factor of zero, as this value proved to be best in the short runs. The results of the computer runs will be discussed in Section 7.2.6.

The table also shows that the first 12 runs contained one case each, while runs 13 to 16 contained a case for each of three years, and runs 17 to 20 contained a case for each of two years.

The computing cost for all 20 runs was about $400.00.

7.2.4 Input data

In Appendix IV, Section 3, the input data decks are shown and explained for run numbers 1, 4 and 16. It is not necessary to read that section unless you wish to see what the actual data decks looked like and how they incorporated the facility and transport information presented above. We are presenting the Niagara study primarily as an example of ALLO2 output and its interpretation.

7.2.5 Printout

In Appendix VII the printout from run no. 16, including all three data cases, is partially shown as an example of typical printout from ALLO2. This is one of the runs for which input data decks were shown in Appendix IV. The results of this and the other runs are summarized and discussed in Section 7.2.6.

Here we shall explain the significance of each part of the printout, emphasizing points which are of special interest to the Niagara study.

The first page of the printout shown in Appendix VII was the same for every run in the study, except for the statement appearing between the symbols "////", which documents the data modification for the run. You will also note on the first page that ALPHA is referred to in the printout as the "travelling factor".

TABLE 15. ALLO2 RUNS MADE IN NIAGARA STUDY

Run No.	Data Modification*	Data Year	Weight Factor	Facility Combinations Evaluated**
1	0	1974	-2	1 only
2	"	"	0	"
3	"	"	+2	"
4	"	"	0	All
5	"	1980	-2	1 only
6	"	"	0	"
7	"	"	+2	"
8	"	"	0	All
9	"	1990	-2	1 only
10	"	"	0	"
11	"	"	+2	"
12	"	"	0	All
13	1	'74,80,90	-2	1 only
14	"	"	0	"
15	"	"	+2	"
16	"	"	0	All
17	2	'80,90	-2	1 only
18	"	"	0	"
19	"	"	+2	"
20	"	"	0	All

* 0 = No modification.
1 = Loading costs raised 50%; vacuum filter size limits raised 50% by 1980, 100% by 1990.
2 = Loading, haulage and O.& M. costs raised 20% by 1980, 60% by 1990.

** When "1 only" is stated, the combination evaluated was that which contains all potential facilities, in order to test the value of the weight factor.

On the second page, the printout states that data case number one is beginning. The data, which were discussed in the preceding section, are printed out with the addition of a few explanatory statements. You will note that the number "22222222" is shown as the size limit for facilities which were given no effective size limit in the data. This is the actual number used by the program for purposes of linear programming. When the total output of sources is larger, as in the 1980 and 1990 data cases, the number used is larger, but is similar in its repetition of digits.

The volume reduction factor given for the drying lagoons is not used, since these facilities are modelled as dead-end facilities, as are the vacuum filters.

The transport information is printed out in a matrix that shows not only the haulage formula indicator and trip length (distance) entered for each link, but also the transport link cost coefficient C ("unit transport cost") calculated by the program, as well as the sum of C and the variable cost B of the facility at the end of the link, giving the link's distribution cost coefficient ("unit variable cost" in the printout), which is used in the optimization of sludge distribution. As would be expected from the data, these coefficients are the same in each of the three data cases. For brevity, only a few of the significant digits in the data are printed out.

At the end of the transport information the printout tells the user how the data are modified for computation, both in terms of scaling and weighting. As would be expected from the data, the weighting routine results in no change in the data in any of the three data cases. However, the scaling results in large changes which are of a different magnitude in the first data case than in the second and third. This difference in magnitude results from the larger source outputs in the second and third data cases.

The effect is that fewer significant digits are retained for computations in the second and third data cases. The precision is, nevertheless, quite adequate. Using integer values for all numbers, computations for the first data case are done in units of dollars per 100,000 gallons for cost coefficients and in units of 100 gallons for sludge volumes. For the second and third data cases, they are done in units of dollars per 10,000 gallons for cost coefficients and units of 1,000 gallons for sludge volumes. As the printout states, total system costs (including fixed charges) within the computations are then 1000 times and 10 times the actual for the first case and the other two cases, respectively.

This information on scaling tells you what kind of precision to expect in the printout of the solutions, which is done in terms of the original units used in the input data. For example, in the first data case, system costs should contain very little error from round-off, etc. since three extra digits (not shown in the printout) were being carried internally. However, in the second and third data cases, such errors may be expected in the last couple of digits, since only one extra digit was being carried internally.

The next item in the printout states the number of facility combinations to be read from the data, or to be considered in the program's combination generating routine. The input data instruct the program that no specific combinations are in the data; so it undertakes to generate all possible combinations. The printout says there are 134217727 combinations to be considered, which is just $2^{27}-1$. Of course, ALLO2 will generate only a small proportion of these since it is later constrained to include certain facilities in every combination.

At this point, the printout also gives the values of ARBOUT and IDUMP, which you recall from the input data are 300 and 1000, respectively. You will note that the printout says a facility combination is being "done with netout" when it means that its sludge distribution is being optimized and printed out before it is screened.

Next the printout states the initial value of C* that it will use for screening. No value for this was entered in the data; so the program uses the number 999999999, the value entered for INF in the block data. Thus, the survey of solutions will obtain its first meaningful value for C* as the total system cost of the first solution evaluated and stored.

Following this is the list of facilities the program is instructed to include in every combination it generates and the maximum values entered in the data for the number of facilities of each type that may exist in a combination. You recall that the latter may be overridden by the former.

On the same page, the printout begins with a facility combination being done with netout. After naming the facilities that belong to the combination, it gives the optimized distribution. You will note that the combination is referred to here as a "subset". Also, all facilities that were to be included in every combination are shown here, even though the total input to many of them is zero.

Between the 900th and the 1200th facility combinations done with netout, the printout states that a data dump was completed after the 1000th facility combination was evaluated. This statement also appears at the end of this data dump, on dataset file unit IW2.

Note that in all three data cases the same six facility combinations are done with netout. This is because the instructions to the program for generating the combinations and for doing combinations with netout were the same each time. It may be useful to compare the optimized sludge distributions for this set of non-optimal solutions in the different cases.

After the 1800th facility combination done with netout, the printout indicates the completion of the survey and details the stored set of best solutions. The 20 stored solutions are then printed out with optimized distributions. Note that no facility in these solutions has zero input.

Finally, the data case is completed by the printout of statistics showing FACSET, the total number of facility combinations evaluated (actually generated within the program) and NSTOR, the number of combinations that passed through all screening and were stored at some time in the set of best solutions. Note that about 60% of all the combinations passed through all screening. This is done to the large value of ESP which, as stated earlier, could have been smaller without changing the results.

The statistics show LINCAL, the number of times linear programming was called upon. Note that this is about 75% of the maximum value it could have (namely 2 x FACSET) if screening never eliminated any facility combinations before they had been submitted to all required linear programming. Therefore, this also indicates a rather low effectiveness in this run.

The statistics also show NOSMMR, the number of facility combinations for which the winter optimization was so inconsiderate of the summer system that, due to their size limits, the summer facilities could not meet the demand put on them. This is zero, as desired and expected.

7.2.6 Results

In this section, the results of the 20 runs in the Niagara study are summarized and discussed. First, we shall deal with those which were short runs to test the value of the weight factor and the correctness of the data.

7.2.6.1 Preliminary short runs. Table 16 summarizes the results of the short runs. Each row of the table gives the result for a particular data case. You will recall that all of these data cases contained only one specified combination of facilities for evaluation: that combination which includes all 27 potential facilities in the mode. The result, therefore, just shows which of the facilities have some input in the optimized sludge distribution. It also shows the total system cost, excluding fixed charges for facilities with zero input. We are not particularly interested here in the exact sludge distribution.

In the table, an "I" in the column under a potential facility name indicates that this facility had input over zero in the optimized sludge distribution. The resulting combination of facilities would be the globally optimal solution for the data case if it were not for the fixed charges in the facility cost functions*. You will see in the next section that, due to the influence of the fixed charges, the 20 least-cost solutions do not include the facility combination shown here in any of the data cases.

These preliminary short runs are useful to observe the influence of the fixed charges. They are also useful because, by checking the data

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* Fixed charges "throw a wrench in the works" because if you take one of these facility combinations and remove a facility from it or replace it with another, the increase in cost of distribution may be more than compensated by a decrease in the total fixed charges.

TABLE 16. SUMMARY OF RESULTS OF PRELIMINARY SHORT RUNS

Run Number	Data Modification	Year	Weight Factor	LAND SPREADING SITES								DRYING LAGOONS								VAC. FILT			HOLDING TANKS								System Cost
				1. Fort Erie	2. Netherby	3. Port Colborne	4. Point Abino	5. Cyanamid	6. Rosedene	7. Wainfleet	8. Caistorville	9. Fort Erie	10. Netherby	11. Port Colborne	12. Point Abino	13. Cyanamid	14. Rosedene	15. Wainfleet	16. Caistorville	17. Port Dalhousie	18. Niagara Falls	19. Welland	20. Fort Erie	21. Netherby	22. Port Colborne	23. Point Abino	24. Cyanamid	25. Rosedene	26. Wainfleet	27. Caistorville	
1	0	74	-2	I		I		I				I		I						I	I										27 (x$10000)
2	0	74	0	I	I	I	I	I	I											I			I		I			I			23
3	0	74	+2	I	I	I	I	I	I														I		I			I			24
5	0	80	-2	I	I	I	I	I	I	I		I	I	I						I	I		I		I		I	I			92
6	0	80	0	I	I	I	I	I	I	I										I			I		I		I	I			90
7	0	80	+2	I	I	I	I	I	I	I													I		I		I	I			91
9	0	90	-2	I	I	I	I	I	I	I		I	I	I						I	I		I		I		I	I			115
10	0	90	0	I	I	I	I	I	I	I										I			I		I		I	I			113
11	0	90	+2	I	I	I	I	I	I	I													I		I		I	I			115
13	1	74	-2	I		I		I				I		I						I	I										29
14	1	74	0	I	I	I	I	I	I											I			I		I			I			25
15	1	74	+2	I	I	I	I	I	I														I		I			I			28
13	1	80	-2	I	I	I	I	I	I	I		I	I	I		I				I	I		I		I		I	I			101
14	1	80	0	I	I	I	I	I	I	I										I			I		I		I	I			98
15	1	80	+2	I	I	I	I	I	I	I													I		I		I	I			104
13	1	90	-2	I	I	I	I	I	I	I		I	I	I		I				I	I		I		I		I	I			125
14	1	90	0	I	I	I	I	I	I	I										I			I		I		I	I			122
15	1	90	+2	I	I	I	I	I	I	I													I		I		I	I			131
17	2	80	-2	I	I	I	I	I	I	I		I	I	I		I				I	I		I		I		I	I			109
18	2	80	0	I	I	I	I	I	I	I										I			I		I		I	I			104
19	2	80	+2	I	I	I	I	I	I	I													I		I		I	I			105
17	2	90	-2	I	I	I	I	I	I	I		I	I	I		I	I			I	I		I		I		I	I			170
18	2	90	0	I	I	I	I	I	I	I										I			I		I		I	I			166
19	2	90	+2	I	I	I	I	I	I	I													I		I		I	I			168

printed out, you could ascertain whether the data were set up properly, thus avoiding the possibility of wasting money on a long complete run with incorrect data. Another check is to look at the solution of the short run to make sure the costs printed out are reasonable.

A very important use of these short runs is to test the value of the weight factor.

For the tests to be meaningful, the solutions should be reasonably close to the near-optimal solutions that are obtained in a complete run. You will see that the relative difference between these system costs and those discussed in the next section is less than 10% in every data case; so this condition is satisfied. If difficulties were expected in satisfying this condition (as would happen if the fixed charges were much larger than in this example), then the short runs should be made with several specific combinations of facilities rather than just one, and the weight factor value which gives the least cost solution out of the restricted survey should be chosen.

In this example, it is obvious that a zero weight factor is better than a value of +2 or -2. Since the value of +2 always gives a system cost very close to that given by the zero value, it is concluded that zero is a good approximation to the optimal weight factor.

7.2.6.2 Complete runs: solutions to consider. Looking at the printout excerpts from run no. 16 in Appendix VII, and realizing that the whole printout for that run constitutes just 30-40% of the entire printout for all the complete runs (no. 4, 8, 12 and 20), you may be overwhelmed by the sheer volume of the entire printout that must be analyzed to obtain meaningful results. This section illustrates a simple process by which initial interpretation of the printout can be carried out to greatly reduce the number of solutions for detailed consideration*.

We are concerned in this section only with facility combinations in the final best solutions for each data case, not with the optimal sludge distribution patterns. The first step is to go through the printout and summarize the least-cost facility combinations in tabular form.

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* In fact, the process illustrated in this section is entirely mechanical and could be carried out by a simple computer program.

Table 17 shows the 20 least cost facility combinations obtained in runs 4, 8 and 12, that is for 1974, 1980 and 1990, respectively, with no data modifications. The cases are placed one under the other to facilitate comparison; and within each case the facility combinations are ranked from top to bottom from best (cheapest) to 20th best.

From the column on the right, giving the total system cost, you can see that the 20 best solutions are very similar in cost within each case. In fact, many more best solutions than 20 might be of interest, if we had the opportunity to do the runs over again.

Patterns of "desirability" of the various potential facilities are clear from this table. Certain facilities appear in every solution, implying that they are quite essential. Predictably, the number of such essential facilities increases over the years. On the other hand, certain facilities do not appear in any of the best solutions. As well as this, certain facilities can be seen to be alternate choices for one another. For example, in the first four solutions for 1974, the Cyanamid holding tank alternates with the Rosedene holding tank, and the Port Colborne holding tank alternates with the Port Colborne drying lagoon.

Another useful observation is that for 1980, pairs of adjacent solutions (i.e. adjacent rows in the table) often differ only in that the Port Dalhousie vacuum filter may or may not be used.

Table 18 summarizes the results of the runs with the first data modification (higher loading costs, increasing size limits on vacuum filters) and Table 19, the second data modification (increasing transport and O & M costs). Facility desirability patterns are also observable in these results.

Such observations are valuable to get an initial feeling for the results.

As well as comparisons within a data case to reveal options that are available without significant changes in cost, comparisons between different data cases for the same year should be made to reveal solutions that are less sensitive to the data and thus more reliable. For instance, for 1974 the facility combinations which rank 15, 16 and 17 with unmodified data (Table 17) do not appear at all in the list of best solutions with data modification number one (Table 18). Modification number two has

TABLE 17. SUMMARY OF COMPUTER RUNS WITH NO DATA MODIFICATIONS, SHOWING THE 20 LEAST COST FACILITY COMBINATIONS FOR EACH OF THREE TIME PERIODS

Run	Year	Rank	1 FELS	2 NELS	3 PCLS	4 PALS	5 CYLS	6 RSLS	7 WFLS	8 CSLS	9 FEDL	10 NEDL	11 PCDL	12 PADL	13 CYDL	14 RSDL	15 WFDL	16 CSDL	17 PDVF	18 NFVF	19 WDVF	20 FEHT	21 NEHT	22 PCHT	23 PAHT	24 CYHT	25 RSHT	26 WFHT	27 CSHT	Cost
4	74	1	I		I		I	I			I		I													I				211 (x$1000)
		2	I		I		I	I			I		I														I			211
		3	I		I		I	I			I													I		I				212
		4	I		I		I	I			I													I			I			212
		5	I		I		I	I			I		I													I	I			214
		6	I		I		I	I			I													I		I	I			214
		7	I		I		I	I		I	I		I													I			I	214
		8	I		I		I	I	I		I															I		I		215
		9	I		I		I	I		I	I													I		I			I	215
		10	I		I	I	I	I			I														I	I				215
		11	I		I	I	I	I			I		I												I		I			215
		12	I		I		I	I	I		I																I	I		216
		13	I		I		I	I	I		I															I	I	I		217
		14	I		I		I	I	I		I								I					I						217
		15	I		I		I	I	I		I														I	I	I			217
		16	I		I		I	I	I	I	I															I		I	I	218
		17	I		I	I	I	I		I	I														I	I			I	218
		18	I		I		I	I			I								I					I		I				218
		19	I		I		I	I	I	I	I								I					I					I	219
		20	I		I			I			I								I					I			I			219
8	80	1	I	I	I		I	I			I		I						I							I	I			803 (x$1000)
		2	I	I	I	I	I	I			I		I													I	I			805
		3	I	I	I	I	I	I			I		I										I			I	I			808
		4	I	I	I	I	I	I			I		I						I				I			I	I			809
		5	I	I	I	I	I	I	I		I														I	I	I			809
		6	I	I	I	I	I	I	I		I								I						I	I	I			809
		7	I	I	I		I	I	I		I								I							I	I	I		810
		8	I	I	I	I	I	I	I		I														I	I	I	I		811
		9	I	I	I	I	I	I	I		I								I						I	I	I	I		811
		10	I	I	I	I	I	I	I		I															I	I	I		813
		11	I	I	I		I	I		I	I		I						I							I			I	814
		12	I	I	I	I	I	I	I		I												I			I	I	I		816
		13	I	I	I	I	I	I	I		I								I				I			I	I	I		816
		14	I	I	I	I	I	I		I	I		I													I			I	816
		15	I	I	I	I	I	I	I		I												I		I	I	I			817
		16	I	I	I	I	I	I	I		I								I				I		I	I	I			817
		17	I	I	I	I	I	I		I	I		I										I			I			I	819
		18	I	I	I	I	I	I		I	I		I						I				I			I			I	819
		19	I	I	I	I	I	I	I	I	I														I	I			I	820
		20	I	I	I	I	I	I	I	I	I								I						I	I			I	820
12	90	1	I	I	I	I	I	I	I		I								I						I	I	I			104 (x$10000)
		2	I	I	I	I	I	I	I		I								I						I	I	I	I		104
		3	I	I	I	I	I	I	I		I		I						I				I			I	I			104
		4	I	I	I	I	I	I	I		I								I				I			I	I	I		105
		5	I	I	I	I	I	I	I		I		I						I							I	I			105
		6	I	I	I	I	I	I	I		I								I				I		I	I	I			105
		7	I	I	I	I	I	I	I		I								I							I	I	I		105
		8	I	I	I	I	I	I	I	I	I								I						I	I			I	105
		9	I	I	I	I	I	I	I		I													I	I	I	I			105
		10	I	I	I	I	I	I	I		I								I					I	I	I	I			105
		11	I	I	I		I	I	I		I								I					I		I	I			105
		12	I	I	I	I	I	I	I	I	I								I						I	I		I	I	105
		13	I	I	I	I	I	I	I	I	I								I						I		I	I		106
		14	I	I	I	I	I	I	I		I													I		I	I			106
		15	I	I	I	I	I	I	I	I	I		I						I				I			I			I	106
		16	I	I	I		I	I	I	I	I								I								I	I		106
		17	I	I	I	I	I	I	I		I												I	I		I	I			106
		18	I	I	I	I	I	I	I		I								I				I	I		I	I			106
		19	I	I	I	I	I	I	I		I														I	I	I			106
		20	I	I	I	I	I	I	I	I	I								I				I			I		I	I	106

TABLE 18. SUMMARY OF COMPUTER RUN WITH DATA MODIFICATION NUMBER 1, SHOWING THE 20 LEAST COST FACILITY COMBINATIONS FOR EACH OF THREE TIME PERIODS.

Run	Year	Rank	1 FELS	2 NELS	3 PCLS	4 PALS	5 CYLS	6 RSLS	7 WFLS	8 CSLS	9 FEDL	10 NEDL	11 PCDL	12 PADL	13 CYDL	14 RSDL	15 WFDL	16 CSDL	17 PDVF	18 NFVF	19 WDVF	20 FEHT	21 NEHT	22 PCHT	23 PAHT	24 CYHT	25 RSHT	26 WFHT	27 CSHT	Cost	
16	74	1	I		I		I	I			I		I													I				237	(x$1000)
		2	I		I		I	I			I		I														I			237	
		3	I		I		I	I			I													I		I				238	
		4	I		I		I	I			I													I			I			238	
		5	I		I		I	I			I		I													I	I			240	
		6	I		I		I	I			I													I		I	I			240	
		7	I		I		I	I		I	I		I													I			I	240	
		8	I		I		I	I	I		I								I					I						241	
		9	I		I		I	I	I		I															I		I		241	
		10	I		I		I	I		I	I													I		I			I	241	
		11	I		I	I	I	I			I														I	I				241	
		12	I		I	I	I	I			I		I												I		I			241	
		13	I		I		I	I			I								I					I		I				242	
		14	I		I		I	I	I		I																I	I		242	
		15	I		I		I	I	I	I	I								I					I					I	242	
		16	I		I			I			I								I					I			I			243	
		17	I		I		I	I	I		I															I	I	I		243	
		18	I		I	I	I	I			I														I	I	I			244	
		19	I		I		I	I			I								I							I				244	
		20	I		I		I	I			I		I						I					I			I	I		244	
	80	1	I	I	I		I	I			I		I						I							I	I			884	(x$1000)
		2	I	I	I	I	I	I	I		I								I						I	I	I			890	
		3	I	I	I	I	I	I			I		I						I				I			I	I			891	
		4	I	I	I		I	I	I		I								I							I	I	I		891	
		5	I	I	I	I	I	I	I		I								I						I	I	I	I		892	
		6	I	I	I		I	I		I	I		I						I							I			I	894	
		7	I	I	I	I	I	I	I		I								I				I			I	I	I		898	
		8	I	I	I	I	I	I	I		I								I				I		I	I	I			899	
		9	I	I	I	I	I	I	I	I	I								I						I	I			I	901	
		10	I	I	I		I	I			I		I						I							I				901	
		11	I	I	I	I	I	I		I	I		I						I				I			I			I	902	
		12	I	I	I		I	I	I	I	I								I							I		I	I	902	
		13	I	I	I	I	I	I	I	I	I								I						I	I		I	I	903	
		14	I	I	I	I	I	I	I		I								I						I	I				908	
		15	I	I	I	I	I	I			I		I						I				I			I				909	
		16	I	I	I		I	I	I		I								I							I		I		909	
		17	I	I	I	I	I	I	I	I	I								I				I			I		I	I	909	
		18	I	I	I	I	I	I	I		I								I						I	I		I		910	
		19	I	I	I	I	I	I			I		I													I	I			910	
		20	I	I	I	I	I	I	I	I	I								I				I		I	I			I	910	
	90	1	I	I	I		I	I	I		I		I						I							I	I			111	(x$10000)
		2	I	I	I	I	I	I	I		I								I						I	I	I			111	
		3	I	I	I	I	I	I	I		I								I						I	I	I	I		112	
		4	I	I	I		I	I	I		I								I							I	I	I		112	
		5	I	I	I	I	I	I	I		I		I						I				I			I	I			112	
		6	I	I	I		I	I	I	I	I		I						I							I			I	112	
		7	I	I	I	I	I	I	I		I								I				I			I	I	I		112	
		8	I	I	I	I	I	I	I		I								I				I		I	I	I			113	
		9	I	I	I	I	I	I	I	I	I								I						I	I			I	113	
		10	I	I	I	I	I	I	I	I	I								I						I	I	I		I	113	
		11	I	I	I		I	I	I	I	I								I				I			I	I		I	113	
		12	I	I	I	I	I	I	I	I	I		I						I							I			I	114	
		13	I		I	I	I	I	I	I	I								I						I		I	I		114	
		14	I		I		I	I	I	I	I								I								I	I		114	
		15	I	I	I	I	I	I	I	I	I								I				I			I		I	I	114	
		16	I	I	I	I	I	I	I	I	I								I				I		I	I			I	114	
		17	I		I	I	I	I	I	I	I		I						I						I		I			115	
		18	I	I	I	I	I	I	I		I								I					I	I	I	I			115	
		19	I	I	I		I	I	I		I								I					I		I	I			115	
		20	I	I	I	I	I	I	I		I								I						I	I				115	

TABLE 19. SUMMARY OF COMPUTER RUN WITH DATA MODIFICATION NUMBER 2, SHOWING THE 20 LEAST COST FACILITY COMBINATIONS FOR EACH OF TWO TIME PERIODS.

Run	Year	Rank	1 FELS	2 NELS	3 PCLS	4 PALS	5 CYLS	6 RSLS	7 WFLS	8 CSLS	9 FEDL	10 NEDL	11 PCDL	12 PADL	13 CYDL	14 RSDL	15 WFDL	16 CSDL	17 PDVF	18 NFVF	19 WDVF	20 FEHT	21 NEHT	22 PCHT	23 PAHT	24 CYHT	25 RSHT	26 WFHT	27 CSHT	Cost	
20	80	1	I	I	I	I	I	I			I		I													I	I			923	(x$1000)
		2	I	I	I		I	I			I		I						I							I	I			925	
		3	I	I	I	I	I	I			I		I										I			I	I			926	
		4	I	I	I	I	I	I	I		I														I	I	I			928	
		5	I	I	I	I	I	I	I		I														I	I	I	I		929	
		6	I	I	I	I	I	I			I		I						I				I			I	I			931	
		7	I	I	I	I	I	I	I		I															I	I	I		932	
		8	I	I	I	I	I	I	I		I								I						I	I	I			933	
		9	I	I	I		I	I	I		I								I							I	I	I		934	
		10	I	I	I	I	I	I	I		I								I						I	I	I	I		934	
		11	I	I	I	I	I	I	I		I												I			I	I	I		935	
		12	I	I	I	I	I	I		I	I		I													I			I	936	
		13	I	I	I	I	I	I	I		I												I		I	I	I			936	
		14	I	I	I		I	I		I	I		I						I							I			I	938	
		15	I	I	I	I	I	I		I	I		I										I			I			I	939	
		16	I	I	I	I	I	I	I		I								I				I			I	I	I		940	
		17	I	I	I	I	I	I	I	I	I														I	I			I	941	
		18	I	I	I	I	I	I	I		I								I				I		I	I	I			941	
		19	I	I	I	I	I	I	I	I	I														I	I		I	I	942	
		20	I	I	I	I	I	I		I	I		I						I				I			I			I	944	
	90	1	I	I	I	I	I	I	I		I								I						I	I	I			151	(x$10000)
		2	I	I	I	I	I	I	I		I								I						I	I	I	I		151	
		3	I	I	I	I	I	I	I		I		I						I				I			I	I			152	
		4	I	I	I	I	I	I	I		I													I	I	I	I			152	
		5	I	I	I	I	I	I	I		I								I				I			I	I	I		152	
		6	I	I	I	I	I	I	I		I								I				I		I	I	I			153	
		7	I	I	I	I	I	I	I		I		I						I							I	I			153	
		8	I	I	I	I	I	I	I		I								I							I	I	I		153	
		9	I		I	I	I	I	I	I	I		I						I						I		I	I		153	
		10	I	I	I	I	I	I	I		I													I		I	I			153	
		11	I	I	I	I	I	I	I		I												I	I		I	I			153	
		12	I		I	I	I	I	I		I		I						I								I	I		153	
		13	I	I	I	I	I	I	I	I	I								I						I	I			I	153	
		14	I	I	I	I	I	I	I		I								I					I	I	I	I			153	
		15	I	I	I	I	I	I	I		I														I	I	I			153	
		16	I	I	I	I	I	I	I	I	I								I						I	I		I	I	153	
		17	I	I	I	I	I	I	I		I														I	I	I	I		153	
		18	I	I	I		I	I	I		I								I					I		I	I			154	
		19	I	I	I	I	I	I	I	I	I		I						I				I			I			I	154	
		20	I	I	I	I	I	I	I		I		I										I			I	I			154	

no effect on the 1974 data case so it need not be considered for the 1974 solutions.

We may carry this type of analysis quite far in order to eliminate a large number of the solutions shown in Tables 17, 18, and 19. Follow the policy that, for a given year or time period, only those facility combinations that occur in the lists of the 20 best solutions for every data modification should be retained. These will be the most "robust" solutions, that is, those that are least sensitive to assumptions about cost functions and, consequently, those that are the most reliable.

In the process of finding the robust solutions, we may record how they rank with each data modification. These results are shown diagrammatically in Figure 33. In this diagram, the numbers from 1 to 20 represent solution rank; these numbers are joined by straight lines if they actually represent the same facility combinations. Such diagrams illustrate the stability of a solution with respect to data modifications. In Figure 33 for 1974 there are 17 lines corresponding to facility combinations that the data modification does not throw out of the 20 best; but the steeper the line is, the more the combination is affected by the modification. Similarly, for 1980 and 1990, three-link paths going right across the diagram correspond to facility combinations that remain in the 20 best no matter which modification is used in the data; but the more unlevel a path is, the more sensitive the combination is to the assumptions about the cost functions. Thus, if we wished, we could further evaluate the facility combinations according to such qualitative indications of robustness.

Let us not adopt a policy that a combination of facilities should not be retained if it cannot be placed in a time sequence of facility combinations for 1974, 1980 and 1990 such that each combination is contained in its successor. This is one possible means of enforcing a criterion of economical continuity: saying that facility combinations can only be added to, not subtracted from within the planning time horizon.

When analyzing this aspect, we may construct a diagram such as Figure 34. In the columns under each year are the robust facility combinations retained as those that remained in the 20 best solutions under all the data modifications. The facility combinations are designated

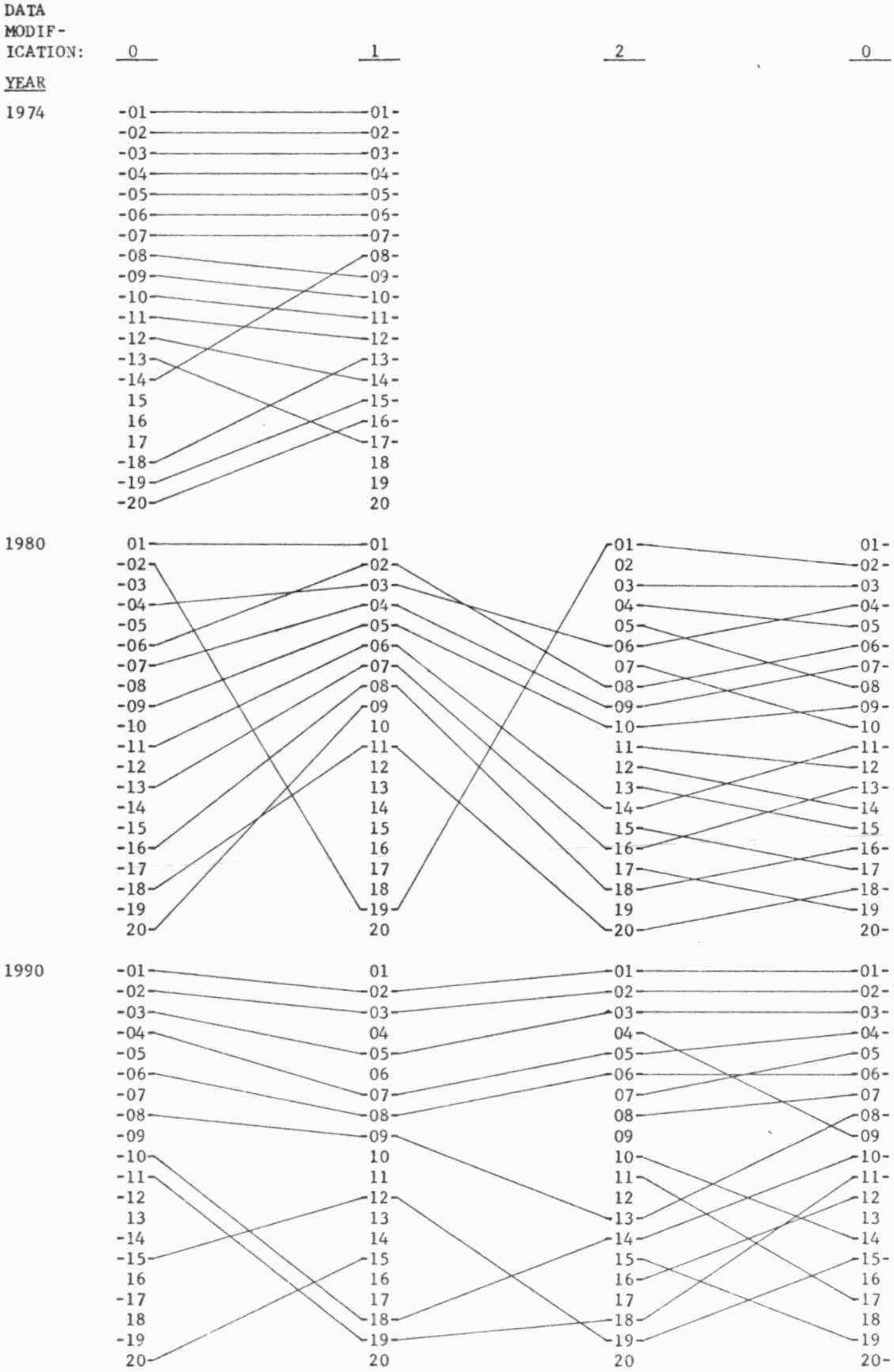

FIGURE 33. MATCHING OF FACILITY COMBINATIONS IN 20 BEST SOLUTIONS FOR A GIVEN YEAR WITH DIFFERENT DATA MODIFICATIONS

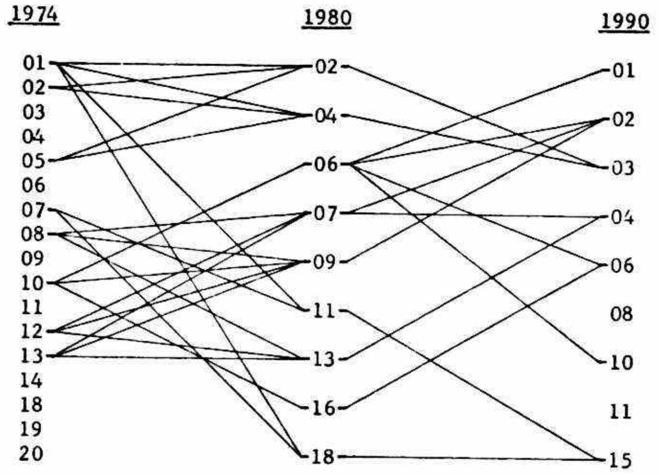

FIGURE 34. RELATING FACILITY COMBINATIONS IN SUCCESSIVE TIME PERIODS SUCH THAT THE LATER COMBINATION CONTAINS THE EARLIER

(Note: Combinations are Designated by their Solution Rank with Zero data Modification.)

TABLE 20. ALL POSSIBLE SOLUTION SEQUENCES OVER TIME AS INDICATED BY FIGURE 34.

	1974	1980	1990
1)	01	02	03
2)	01	04	03
3)	01	11	15
4)	01	18	15
5)	02	02	03
6)	02	04	03
7)	05	02	03
8)	05	04	03
9)	07	11	15
10)	07	18	15
11)	08	07	02
12)	08	07	04
13)	08	09	02
14)	08	13	04
15)	10	06	01
16)	10	06	02
17)	10	06	06
18)	10	06	10
19)	10	09	02
20)	10	16	06
21)	12	07	02
22)	12	07	04
23)	12	09	02
24)	12	13	04
25)	13	07	02
26)	13	07	04
27)	13	09	02
28)	13	13	04

by their rank number with zero data modification (as shown in Table 17). A number is connected by a straight line to another number on its right if the facility combination it represents is contained in the facility combination that the number on its right represents. Such a diagram illustrates the flexibility of facility combinations with respect to future development. Paths of development through time can be traced from 1974 to 1990 by following the lines from left to right. The more alternatives that grow out of a facility combination, the more flexible it is. You can see that some facility combinations do not occur on any path at all; so they are not eliminated.

Table 20 lists all possible paths of development implied in Figure 34, again designating the facility combinations by their rank numbers as shown in Table 17. You can see that there are 28 different possible paths. We have numbered them for latter reference.

Table 21 lists the facility combinations now remaining for each year. For simplicity, facilities that do not occur in any of these solutions are omitted from the table headings. We can now restrict attention to the 24 solutions in this table, a much easier task than considering the 160 solutions listed in Tables 17, 18 and 19.

TABLE 21. SOLUTIONS REMAINING FOR DETAILED CONSIDERATION

YEAR	RANK WITH DATA MODIFICATION			1 FELS	2 NELS	3 PCLS	4 PALS	5 CYLS	6 RSLS	7 WFLS	8 CSLS	9 FEDL	11 PCDL	17 PDVF	21 NEHT	22 PCHT	23 PAHT	24 CYHT	25 RSHT	26 WFHT	27 CSHT	SYSTEM COST WITH DATA MODIFICATION			UNITS
	0	1	2																			0	1	2	
74	1	1		I		I		I	I			I	I					I				211	237		(x$1000)
	2	2		I		I		I	I			I	I						I			211	237		
	5	5		I		I		I	I			I	I					I	I			214	240		
	7	7		I		I		I	I		I	I	I					I			I	214	240		
	8	9		I		I		I	I	I		I						I		I		215	241		
	10	11		I		I	I	I	I			I					I	I				215	241		
	12	14		I		I		I	I	I		I							I	I		216	242		
	13	17		I		I		I	I	I		I						I	I	I		217	243		
80	2	19	1	I	I	I	I	I	I			I	I					I	I			805	910	923	(x$1000)
	4	3	6	I	I	I	I	I	I			I	I	I	I			I	I			809	891	931	
	6	2	8	I	I	I	I	I	I	I		I		I			I	I	I			809	890	933	
	7	4	9	I	I	I		I	I	I		I		I				I	I	I		810	891	934	
	9	5	10	I	I	I	I	I	I	I		I		I			I	I	I	I		811	892	934	
	11	6	14	I	I	I		I	I		I	I	I	I				I			I	814	894	938	
	13	7	16	I	I	I	I	I	I	I		I		I	I			I	I	I		816	898	940	
	16	8	18	I	I	I	I	I	I	I		I		I	I		I	I	I			817	899	941	
	18	11	20	I	I	I	I	I	I		I	I	I	I	I			I			I	819	902	944	
90	1	2	1	I	I	I	I	I	I	I		I		I			I	I	I			104	111	151	(x$10000)
	2	3	2	I	I	I	I	I	I	I		I		I			I	I	I	I		104	112	151	
	3	5	3	I	I	I	I	I	I	I		I		I	I			I	I			104	112	152	
	4	7	5	I	I	I	I	I	I	I		I	I	I	I			I	I	I		105	112	152	
	6	8	6	I	I	I	I	I	I	I		I		I	I		I	I	I			105	113	153	
	10	18	14	I	I	I	I	I	I	I		I		I		I	I	I	I			105	115	153	
	15	12	19	I	I	I	I	I	I	I	I	I	I	I	I			I			I	106	114	154	

7.2.6.3 Summary of the results. The results of the Niagara study warrant a whole report by themselves, rather than just these few sections. The solutions would have to be judged in the light of qualitative factors that a computer cannot handle and the further ramifications of each promising solution, such as the sludge transport system it requires. On the basis of such evaluations, recommendations would be made on data for additional computer runs or for acceptance of a final plan. The procedure was discussed in Chapter 3.

Here, however, we can show a quantitative interpretation of the direct results of the computer runs and make generalizations on them that will demonstrate the type of input the computer runs give to the engineer in his planning task.

After reducing the number of solutions for consideration, as in the preceding section, the retained solutions can be examined in detail with respect to the optimized sludge distribution patterns given in the printout. It is found that the distribution patterns for the different solutions are all small variations on a few basic patterns. Simplified distribution maps, such as the one shown in Figure 35 (seventh ranking facility combination for 1974 with no data modification), can be drawn to aid visualization.

We find that for every facility combination listed in Table 21, the data modifications have no effect on the optimized sludge distribution, with one exception: when the vacuum filter size limits are raised for 1980 and 1990 in data modification no. 1 in facility combinations containing the Port Dalhousie vacuum filter. This allows the Port Weller/Port Dalhousie source (PWDH) to send more sludge to this vacuum filter and less to the distant Cyanamid holding tank (CYHT). In turn, this lightens the load on some land spreading sites from PWDH and CYHT and may also affect the distribution from the Niagara Falls source among these sites. However, the distribution picture remains virtually the same.

This is further evidence of the stability of these solutions or facility combinations relative to variations in the data.

Recalling that the drying lagoons and vacuum filters have ultimate disposal to certain land spreading sites assumed in their O & M costs, we now check for such facilities in these solutions to see where this

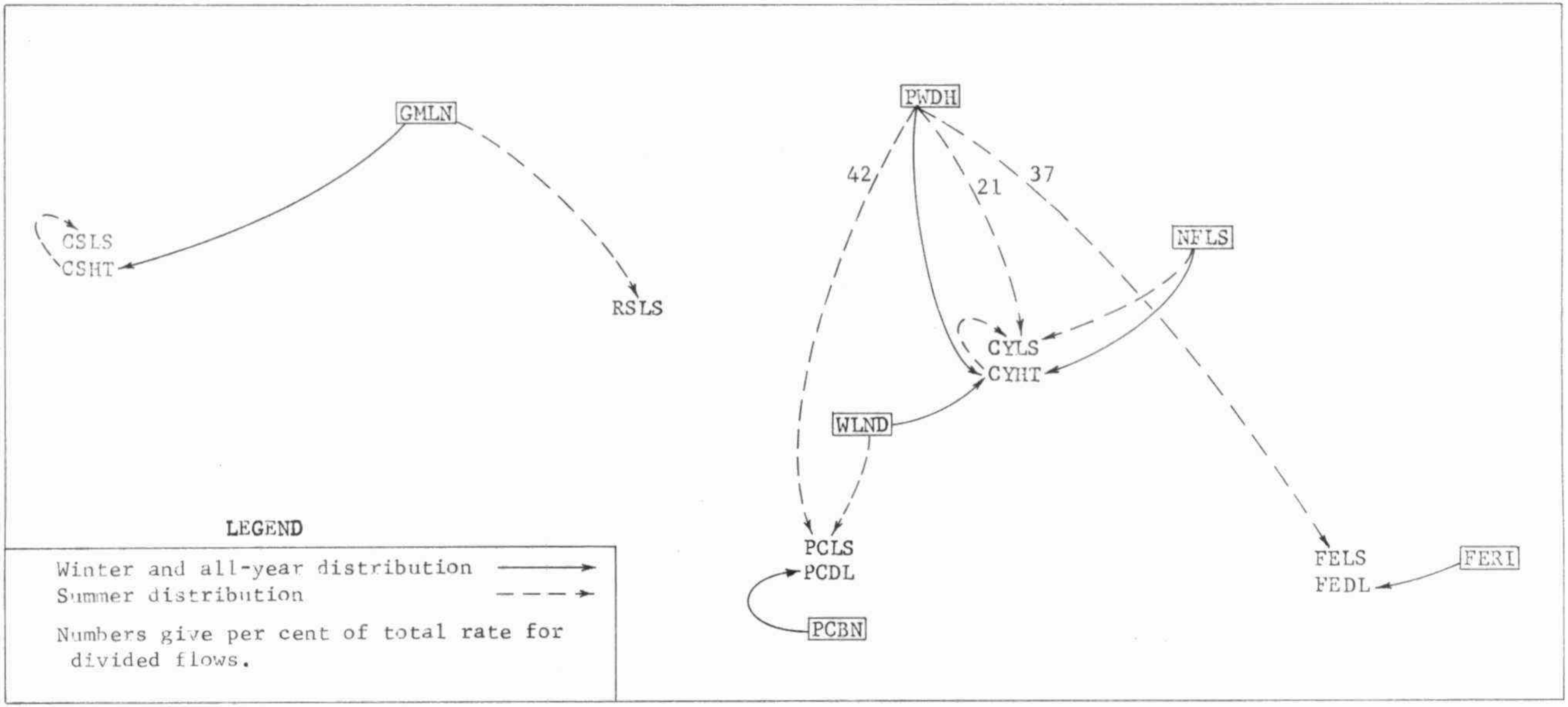

FIGURE 35. SIMPLIFIED MAP OF SLUDGE DISTRIBUTION FOR THE 7th RANKING FACILITY COMBINATION FOR 1974 WITH ZERO DATA MODIFICATION

hidden disposal is going. To be conservative, we use the sludge distribution patterns without the raised vacuum filter size limits. Thus, we find that the actual total input to the Fort Erie land spread site is over its size limit in every solution: 3% over in six 1974 solutions and 43% over in two; 43% over in one 1980 solution and 115% over in eight; and 115% over in seven 1990 solutions. In addition, we find that in some solutions the size limit is also exceeded on the Port Colborne land spread in terms of actual total input: 11% over in three 1974 solutions and 20% over in one; 39% over in four 1980 solutions and 43% over in two 1990 solutions. This is summarized in Table 22.

This is not a difficult matter, however. If the excess allocation is deemed large enough to invalidate a solution, we need only rearrange the sludge distribution slightly to eliminate it. Since the other land spreading sites have size limits 10 times the size of Fort Erie or Port Colborne, several of which are quite close (eg. Netherby and Point Abino), a small alteration of the sludge distribution would suffice and the system cost would not change significantly*.

Next, we might take a closer look at the continuity of the solution sequences listed in Table 20. It is possible to evaluate solutions in terms of how well they blend into one another in the time sequence. One quantitative criterion that can be used is an extension of that used in the preceding section: if the total annual input to a facility decreases from one time period to the next, the solution could be questionable. A good justification would have to be found for a solution that contains a facility that must be established at some point for a much larger capacity than it needs in the future. Thus, for example, the sequences in Table 20 numbered 1, 2, 5, 6, 7 and 8 have the Rosedene land spreading site used in 1990 only half as much as in 1980. The same may be said for the Rosedene holding tank in sequence numbers 21, 22, 23 and 24; and the Point Abino holding tank in sequence numbers 16 and 18. A similar situation, though not as extreme, holds for the Point

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* Recall that such manual alteration of solutions is necessary here because in the Niagara study we are modelling a situation (namely the ultimate disposal of dewatered sludge by agricultural land spreading) that does not match exactly with the ideal problem ALLO2 was designed for (see section 2.2 of this chapter). However, it should be clear that this has not created any serious obstacles.

TABLE 22. PERCENT BY WHICH ACTUAL TOTAL INPUT EXCEEDS SIZE LIMIT ON FORT ERIE AND PORT COLBORNE LAND SPREADING SITES DUE TO HIDDEN ULTIMATE DISPOSAL FROM DEWATERING FACILITIES

YEAR	SOLUTION	FORT ERIE	PORT COLBORNE
1974	1	3	11
	2	43	20
	5	3	11
	7	3	11
	8	3	0
	10	3	0
	12	43	0
	13	3	0
1980	2	43	39
	4	115	39
	6	115	0
	7	115	0
	9	115	0
	11	115	39
	13	115	0
	16	115	0
	18	115	39
1990	1	115	0
	2	115	0
	3	115	43
	4	115	0
	6	115	0
	10	115	0
	15	115	43

Abino holding tank in sequence no. 17. Thus, we may conclude that attention should be concentrated on the remaining sequences which are:

1974	1980	1990
1	11	15
1	18	15
7	11	15
7	18	15
10	6	1
10	9	2
10	16	6

1974	1980	1990
8	7	2
8	7	4
8	9	2
8	13	4
13	7	2
13	7	4
13	9	2
13	13	4

As usual, we are designating facility combinations by their rank number with zero data modification.

Now there are only 15 sequences, starting from five 1974 solutions, certainly a manageable number to study in order to visualize what they each mean in terms of planning. For instance, consider the simplified sludge distribution maps of solutions 8 (for 1974), 7 (for 1980) and 2 (for 1990) in Figure 36 (a), (b), and (c), respectively. In 1974 the six sources share holding tank and land spreading facilities at five sites. Only Grimsby-Lincoln has a land spreading facility all to itself, and only Port Colborne has a holding tank all to itself.

By 1980 (Figure 36(b)), the system has changed significantly: the larger output of Port Weller/Port Dalhousie is split between the on-site vacuum filter and the Cyanamid holding tank in the winter or Netherby land spreading site in the summer, and that of Fort Erie is split between its neighbouring drying lagoon and the Cyanamid holding tank in the winter or Fort Erie land spreading site in the summer, while Grimsby-Lincoln and Port Colborne each have a location all to themselves for a holding tank and land spreading site. We might say that, in this phase, the demand centred among the four north-eastern sources has monopolized the facilities in that area and forced the others to establish their own.

In 1990 (Figure 36(c)), the system is much the same except that the Cyanamid holding tank has such a big winter inventory that Niagara Falls can no longer use Cyanamid in the summer, and must use the Netherby

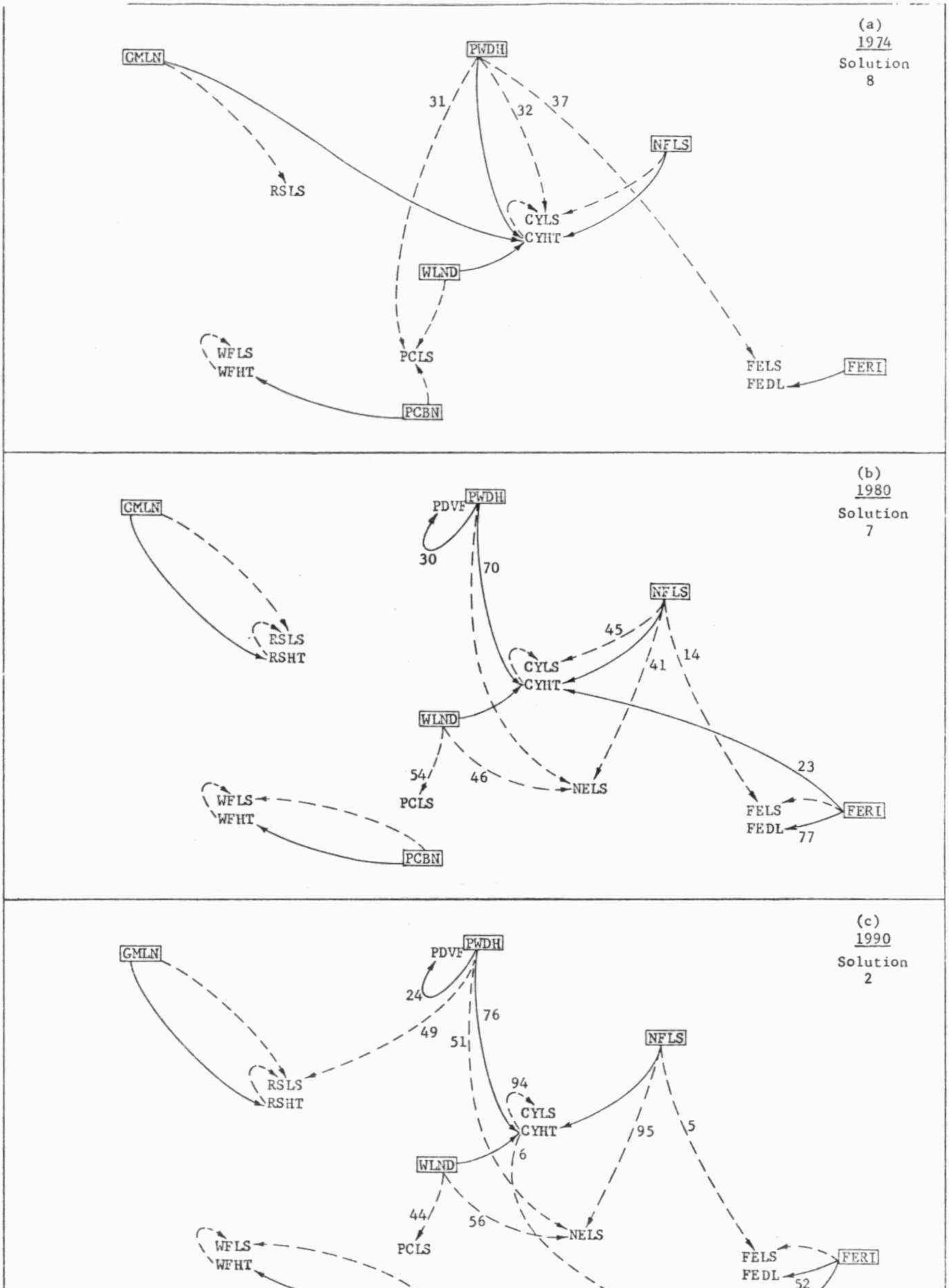

FIGURE 36. SIMPLIFIED MAPS OF SLUDGE DISTRIBUTION FOR THREE SOLUTIONS THAT FORM A TIME SEQUENCE

(See Figure 35 for Map Legend)

land spreading site instead. This pushes some of the summer flow out of Port Weller/Port Dalhousie from Netherby over to Rosedene (so that Grimsby-Lincoln no longer has sole use of that location). Similarly, Fort Erie can no longer use Cyanamid; so Point Abino is added for its use and to help relieve the Cyanamid holding tank.

If solution 4 were used for 1990 instead of 2, the only difference would be that the holding tank used by Fort Erie would be located at Netherby instead of Point Abino.

Fort Erie could have its Point Abino and/or Netherby facilities, as in solutions 2 or 4 for 1990, already in 1980 if solution 7 for 1980 is replaced by solution 9 or 13, respectively.

These alternatives for development, starting with solution 8 for 1974, also hold if you start with 13. The only difference is that then Grimsby-Lincoln already has its own holding tank at Rosedene in 1974.

A good grasp of the solution sequences is readily developed at this point. The planner must look at the sequences which interest him and work out the actual cost of each one, reducing the capital cost of facilities in 1990 that already exist in 1980 and so on. He may decide that specific combinations of facilities that interest him now should be run with ALLO2 using different cost functions or facility size limits, to obtain more accurate optimal sludge distribution patterns and economic comparisons. Or he may be able to select a plan well enough without further computer runs. In any case, he is in the excellent position of having 10 or 20 solutions before him which he could not have obtained manually. On the basis of the reasonable assumptions that produced the model and the cost functions, these solutions are the best among a choice of thousands.

REFERENCES

Domschke, W., 1973a, "Two Algorithms to Detect Negative Cycles in a Valued Diagraph" and "ALGOL Procedures for Two Methods for Detecting Negative Cycles in Valued Diagraphs", Computing 11, 125 - 136 and 169 - 173 (in German).

Domschke, W., 1973b, "Two New Algorithms for Minimal Cost Flow Problems", Computing 11, 275 - 285.

Hadley, G., 1962, "Linear Programming", 351 - 367, Addison-Wesley.

Hahn, H.H., Meier, P.M. and Orth, H., 1973, "Regional Wastewater Management Systems", Part I, Chapter 2 in Deininger, R.A. (ed.), "Models for Environmental Pollution Control", Ann Arbor Science Publishers, Inc.

Imhoff, K. and Fair, G., 1956, "Sewage Treatment", John Wiley & Sons, New York.

Ontario, 1971, "Summary of Sludge Disposal at OWRC Operated Plants", Section 3 of a report apparently published by the OWRC in 1971 (excerpt supplied from proprietary material by the Ontario Ministry of the Environment).

Ontario, 1973, "Water Pollution Control: Operating Summary 1972", Ontario Ministry of the Environment, Project Operation Branch.

Patterson, W. and Banker, R., 1971, "Estimating Costs and Manpower Requirements of Conventional Wastewater Treatment Facilities", Black and Veatch Consulting Engineers, Kansas City, Missouri, for U.S. Environmental Protection Agency, Project 17090DAN.

Southam, 1973, "Water and Pollution Control: Directory Issue 1973", Southam Business Publications Ltd.

Viraraghaven, T., 1972, "Canada Prepares for the Future", Water and Wastes Engineering, October, 1972, 36 - 38.

APPENDIX I

PROJECT HISTORY

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PROJECT HISTORY

The origin of this manual goes back to April, 1972 and a series of letters and discussions between Professor P. L. Silveston of B & P Silveston, Engineers, Claude Langlois, then the Executive Director of the Canadian Federation of Mayors and Municipalities (CFMM) and Roger Gosselin, a research officer with the Federation. As an outcome of the exchange of ideas, the CFMM joined B & P Silveston, Engineers, in a proposal, "Development of a Computer-Aided Technique for Design of Regional Sludge Disposal Systems", submitted to the Technical Committee established under the provisions of the Canada-Ontario Agreement on Great Lakes Water Quality for possible inclusion in the research program funded through the Agreement. An important component of the Research program was the handling and disposal of sewage sludge. The proposal was submitted toward the end of 1972 to Gordon Van Fleet, Secretary of the Technical Committee.

The BPSE-CFMM proposal was accepted by the Technical Committee for the 1974 fiscal year and funded in June, 1973. The objectives in the first year of the contract were a review of existing planning programs, development of a computer-based sludge disposal planning procedure and writing a computer program to handle the economic evaluation of disposal alternatives. Guidelines for the types of systems to be considered by the computer program were devised by the project co-director (on behalf of CFMM), W.L. Keay, Director, Pollution Control Division, Regional Municipality of Ottawa-Carleton; Professor P.L. Silveston, project co-director for BPSE; B.I. Boyko of the Ontario Ministry of the Environment and Dr. E.E. Shannon of the Canada Department of the Environment. Mr. Boyko and Dr. Shannon, both research officers for their agencies, were the contract liaison officers for the two governments.

Phillip Woods served as project officer for the first four months of the project. He was replaced by F. James Allan in September 1973. Mr. Allan developed the ALLO2 program described in this manual. During the first year, Jim Allan was assisted by Mr. P.E.L. Williams, Mrs. Gaye Henry and Mrs. Bonnie Armour.

Work in the first year is described in a report entitled "Development of a Computer-Aided Technique For the Design of Regional Sludge Disposal Systems For The Abatement of Municipal Pollution", dated March 31, 1974 and submitted to the Canada Department of the Environment. Two sections of this report deal with areas which are not described to any extent: 1) a review of the waste disposal planning literature; and, 2) a study of the uniformity of sludge production in waste treatment plants. It was found that planning programs exist for the planning of sewage treatment facilities on a regional basis and for planning dump sites for solid wastes. Because of the capacity of digesters, drying lagoons and other sludge-holding facilities in treatment plants, the shipment of sludge from a treatment plant can be considered as uniform throughout the year. The 1974 report also contained a study of the cost of sludge dipsosal facilities, and of sludge transport. Portions of the study are included in this manual.

In April, 1974, the second year of the project was funded. The objectives in the second year were testing the ALLO2 planning program by application to a real sludge disposal problem, program modification and preparation of this manual, and development of a sludge transport scheduling program. Arrangements were made through Ted Simonen, Pollution Control Director for the Regional Municipality of Niagara, to examine sludge disposal in the region as a test of the ALLO2 program. The Region, at the time these arrangements were made, had a study of sludge disposal under way.

Size of the sludge disposal problem in Niagara in terms of the number of sources and the number of possible facilities to be considered could not be handled efficiently by the ALLO2 program developed in the first year of the project. Attempts to patch the program proved to be insufficient and, as a consequence, large parts of the program had to be rewritten. The revised version is that which is in the manual. Sludge production information, disposal facility types and possible location, as well as facility and transport costs were furnished to BPSE by the Regional Municipality. Studies performed are described in Chapter 7.

Assisting Mr. F.J. Allan, the project manager, was Mrs. Karin Voisin. Liaison officers for the second year were Mr. Gerry Rupke, Ontario Ministry of the Environment and Mr. W.E. Stepko of the Canada Department of the Environment.

Testing and any needed modification of the sludge transport scheduling program remain to be undertaken. A six-month extension of the project to cover these phases has been requested.

APPENDIX II

ABRIDGEMENT OF A 1974 J.F. MACLAREN, LIMITED PAPER ON LANDFILL SITE SCREENING

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ABRIDGEMENT OF A 1974 J.F. MACLAREN, LIMITED PAPER ON LANDFILL SITE SCREENING*

SELECTION CRITERIA, METHODS AND SCORING SYSTEM FOR SANITARY LANDFILL SITE SELECTION

by

D.P. Sexsmith, T.M.A. Wilson and R.G. Graham**

Sanitary landfilling of refuse is the most prevalent disposal method currently in use. Experience has shown that establishing sanitary landfills in accordance with increasingly stringent regulatory procedures is a very difficult and time-consuming operation fraught with strong opposition by special interest groups and the public in general.

The most significant and widely accepted development in the solid waste management field in recent years has been the recognition that waste disposal systems should be established on a regional basis. To permit eventual designation of specific sites for disposal purposes a large number of potential sites must be investigated. It is essential that the investigation be logical and systematic, and that the procedure be well-documented to illustrate that the sites eventually selected have not been chosen arbitrarily.

The site investigation involves a detailed evaluation of all physiographic and environmental conditions pertaining to the location and operation of a sanitary landfill. Initially, all information pertinent to the study area is collected and reviewed, including topographic mapping; soil, geologic and groundwater reports or base data; land use and demographic planning; recreation and conservation studies.

Experience has shown that the interpretation of aerial photography provides a relatively quick and inexpensive means of conducting the preliminary site investigation in order to inventory all available data, and in some cases, to carry out a complete terrain analysis where no background information is available. By initially studying small scale air photos (1" = 1 mile or greater), areas obviously unsuitable for landfill development can be eliminated from a more detailed evaluation.

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* Unpublished paper available through J.F. MacLaren, Ltd.

** Group Manager, Project Manager and Project Engineer, respectively.

The principal physical parameters considered in determining the suitability of sites for sanitary landfill include the type and abundance of cover material (usually the determining factor in site capacity determinations), surface and groundwater characteristics, isolation, and physiography of the area. Other important factors which must be considered are the public acceptability of the facility location, appearance, truck traffic, noise, dust, the potential damage to the existing ecologic regime, the compatability of the site with future land use goals, the ability to control gas release, and the minimization of engineering design and operational problems.

Detailed site selection and evaluation is accomplished by the analysis of large scale airphotos (1" = 1,000').

It should be noted that the air photo analysis is not meant to replace ground surveys, but rather to increase their efficiency and effectiveness. Field checks are carried out to provide verification of existing data or to resolve outstanding questions. With all of this information at hand it is then possible to proceed to the specific site selection phase of the exercise.

There are very seldom perfect sites available; most sites usually have both good and bad features. In order to keep the many unique characteristics of a large number of potential sites in an orderly, relative perspective, a scoring system based on noneconomic factors has been developed.

In essence, the establishment and use of a site must be based on certain objectives. For the purpose of the model, objectives are developed such that they must be attainable and the degree of attainment must be measurable. Within this context a great number of objectives can be determined. These objectives are listed in order of importance and a value is assigned to the objective to reflect its relative importance. Once this is accomplished, experience has shown that many of the originally listed objectives are insignificant and should therefore be discarded.

Having listed the objectives, criteria can then be developed for each which measure the ability of a site to attain that objective. The criteria for each objective can then be arranged and assigned numerical values reflecting not their individual significance, but their relative ability to measure most exactly the attainment of the objective.

With the scoring model developed all sites can be compared relative to one criteria by assigning a numerical value reflecting the site's ability to satisfy the criteria being examined. (If a site cannot meet the objective being examined, it is eliminated from further consideration.) Various specialists can score the sites under criteria involving their area of expertise. For example, planners may be used to score those criteria related to land use.

A useful test of the value of the criteria in the model is made by having several knowledgeable persons score the same site under a specific criterion. If the resultant scores are erratic it is probable that the criterion is not valid and it should be discarded. A computer solution has been developed to translate the individually assigned numerical scores under each criteria to a prorated score for the site, reflecting the assigned relative values of the criteria and objectives as previously established.

As an example, an actual scoring model used on a study in the Ottawa-Hull, National Capital area may be examined. The objectives and their ratings are as follows:

The site must not endanger public health or safety	1000
The site must be acceptable to the public	800
Impairment of the site ecology must be avoided	500
The usage of the site must be compatible with the accepted land use planning in the area	500
The site must be suitable for ready development and operation as a landfill	300

Table 23 is a display of the objectives and related criteria with the assigned relative ratings.

In reviewing Table 23 it may be noted that in the case of "public health and safety" it was determined that the criterion which best measures the attainment of the objective was "freedom from the hazard of groundwater pollution". This criterion was given the maximum rating of 10 and the others were rated relatively, with the least sensitive being assigned

TABLE 23. SANITARY LANDFILL SITE SCORING SYSTEM

Principal Objectives of Sanitary Landfill	Rating by Order of Importance	Criteria		Relative Rating
1. Public Health and Safety (HLTH & STY)	1000	Groundwater Pollution Hazard	(GWHZ)	10
		Gas Travel Hazard	(GAS)	8
		Groundwater Pollution Potential	(GWAT)	8
		Surface Water Pollution Potential and Hazard	(SWAT)	6
		Dust, Noise and Odour Hazards	(ODOR)	1
		Traffic Access Hazard Potential	(TRAF)	1
2. Public Acceptability (PUB ACPT)	800	Isolation From Sight	(ISOL)	10
		Access Roads	(TRAF)	8
		Isolation From Noise, Dust, Odour ..	(ODOR)	6
		Surface Water Pollution Potential...	(SWAT)	4
		Desirability & Benefit of site as Completed Landfill	(FUTE)	2
		Desirability of Improved Land Use ..	(IMPL)	1
3. Ecological Consideration (ECOLOGY)	500	Type and Density of Vegetation	(VEG)	10
		Influence of Existing Development in The Surrounding Area on Species, Variety and Density	(DIST)	2
4. Area Planning and Development Compatibility (Land Use)	500	Compatibility of Completed Fill Area with Future Land use Plans	(FUTE)	10
		Desirability of Improving the Existing Land Use	(IMPL)	5
5. Operation and Finishing Facility (OP & FIN)	300	Life of Site	(CAP)	10
		Availability of Cover Material on Site	(COV)	5
		Ability to Divert Surface Water	(DWAT)	5
		General Accessibility of Site	(TRAF)	2

the value of one. It is noted that although a criterion such as that dealing with "traffic" rated low from the safety and health aspect, it was rated quite high when "public acceptability" was considered.

The scoring is best done by considering one criterion for each site and scoring all sites prior to proceeding to the next criterion. Each criterion is given a score ranging from 1 to 10 with the higher score representing the desirable direction. Thus, a site with no "potential groundwater pollution hazard" for example, would receive a score of 10.

When all criteria have been considered for each site the scores are weighted and the sites are listed in order of descending total score. Table 24 indicates the computer output for some of the sites considered in the National Capital area. The score shown for each site provides an indication of the order of desirability relative to another site; these should not be construed, however, as a measure of how much better one site is than another.

Having determined the best six or eight sites by the scoring technique, it is then possible to select the best site on an economic basis. The first step in doing so is the determination of the cost to develop and eventually finish the sites. This involves the preliminary design of each site which once again makes use of the mapping, records and photographs to establish site capacities, drainage requirements, natural site screening, etc.

Having determined all development and finishing costs, it is then possible to make an economic assessment of the sites to establish the best site from a total system cost viewpoint. The economic analysis represents the culmination of the many individual investigations associated with a solid waste disposal study inasmuch as it combines the results of investigations to determine future population and land use, potential waste generation rates, existing and future transportation networks, haulage costs, processing and disposal facility operating costs and processing plant capital costs. Thus, the eventual landfill site selection is based on such factors as the economics of refuse haulage and the source of refuse generation as well as the operating and development costs for the site.

TABLE 24. COMPUTER PRINTOUT OF SCORE SUMMARIES FOR BEST NINE LANDFILL SITES

JAMES F. MACLAREN LTD - SCORING SYSTEM - JAN/06/73

NATIONAL CAPITAL AREA SOLID WASTE MANAGEMENT STUDY (1584)

GENERAL		CHARACTERISTIC	MAX	LANDFILL SITE SELECTION								
OBJECTIVES	WEIGHT	NAME	SCORE	09	08	11	20	10	01	02	05	17
1 HLTH &STY	1000.00	GWMZ	294.11	264.70	264.70	205.88	205.88	205.88	147.05	147.05	147.05	29.41
		GAS	235.29	235.29	235.29	211.76	188.23	211.76	235.29	211.76	235.29	211.76
		GWAT	235.29	211.76	211.76	141.17	70.58	211.76	23.52	23.52	23.52	70.58
		SWAT	176.47	52.94	52.94	105.38	105.68	70.58	105.88	105.88	52.94	70.58
		ODOR	29.41	29.41	29.41	29.41	20.58	29.41	17.64	20.58	26.47	14.70
		TRAF	29.41	26.47	29.41	26.47	23.53	26.47	29.41	29.41	29.41	20.58
		OBJECTIVE TOTAL	1000.00	820.59	823.53	720.59	614.70	755.08	558.02	538.23	514.70	417.64
2 PUB ACPT	800.00	ISOL	258.06	232.25	256.06	206.43	232.25	258.06	180.64	206.45	258.06	232.25
		TRAF	206.45	185.80	206.45	185.80	103.22	165.80	165.16	165.16	123.87	103.22
		ODOR	154.83	139.35	154.83	139.35	139.35	139.35	123.67	123.87	154.83	123.87
		SWAT	103.22	51.61	51.61	72.25	72.25	51.61	61.93	61.93	20.64	51.61
		FUTE	91.61	30.96	25.60	30.96	41.29	5.16	30.96	30.96	28.80	10.32
		IMPL	25.80	2.58	2.58	2.58	7.74	2.58	2.58	2.58	2.58	2.58
		OBJECTIVE TOTAL	800.00	642.58	699.35	637.42	596.13	642.58	565.16	590.97	585.80	523.87
3 ECOL OCY	500.00	VEG	416.66	375.00	375.00	375.00	291.66	291.66	333.33	333.33	375.00	83.33
		DIST	83.33	25.00	8.33	33.33	66.66	33.33	33.33	25.00	8.33	25.00
		OBJECTIVE TOTAL	500.00	400.00	383.33	408.33	358.33	325.00	366.66	358.33	383.33	108.33
4 LAND USE	500.00	FUTE	333.33	200.00	165.66	200.00	265.66	33.33	200.00	200.00	166.66	66.66
		IMPL	166.66	16.66	16.66	15.56	50.00	16.66	16.66	16.66	16.66	16.66
		OBJECTIVE TOTAL	500.00	216.66	183.33	216.66	316.66	50.00	216.66	216.66	133.33	83.33
5 OP& FIN	300.00	CAP	136.36	13.63	13.63	54.54	27.27	136.36	122.72	95.45	34.34	13.63
		COV	68.16	20.45	20.45	20.45	34.09	20.45	13.63	13.63	20.45	27.27
		DWAT	68.18	68.18	68.18	54.54	47.72	61.36	68.18	68.18	68.18	34.09
		TRAF	27.27	16.36	2.72	13.63	13.63	13.63	21.81	21.81	2.72	13.63
		OBJECTIVE TOTAL	300.00	118.63	105.00	143.18	122.72	231.82	226.36	199.09	145.91	88.63
		TOTAL SCORE	3100.01	2198.48	2194.56	2126.19	2008.57	2005.29	1933.69	1903.30	1813.09	1221.82
		POSITION		1	2	3	4	5	6	7	8	9

In summary, the use of the data available to the hydrogeologist and the photointerpreter will permit the location of potential sanitary landfill sites in a relatively short time and at reasonable cost. The utilization of a scoring model in assessing the sites provides an objective method of evaluation and results in a useful documentation of the study methods. With minor alterations, the scoring techniques can be adapted to suit a multitude of investigative situations. Our experience in utilizing this type of model in some six different studies has been that, in spite of the initial impression of complexity, the principles are readily undersood and the results are accepted as being meaningful.

APPENDIX III

DATA ON AVERAGE COSTS IN ONTARIO

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DATA ON AVERAGE COSTS IN ONTARIO

III.1 Introduction

This appendix presents some work done in 1974 to obtain correlations of average sludge transport cost versus distance, and average facility cost versus size. The results are realistic for the average situation in Ontario. They can be used for cost functions in the ALLO2 program when the user is uncertain about the numbers for his specific application: he may find it useful to compare his solutions with those which would be obtained if "typical" numbers were valid.

Caution must be used, however, since for local circumstances the provincial average may be significantly incorrect. A deviation of 20% for facility cost, or 50% for transport cost is not uncommon and this can significantly change the solutions. Important decisions affecting implementation should not be based on results of a study using provincial average data alone.

III.2 Transport Cost

The cost of transporting sludge from a source or facility to another facility is assumed to depend primarily on the distance, the volume transported and the mode of transportation. Since we have limited our modes of transportation to trucking as far as obtaining costs is concerned, this factor is tantamount to sludge concentration, that is, whether tank trucks or open trucks are used. Thus, there is one correlation for liquid sludge (tank trucks) and one for solid sludge (open trucks).

The data collected for the correlations are tabulated in Table 25. The primary source for these data was a 1971 OWRC report (Ontario, 1971). Some data were also obtained directly from pollution control plants which were selected from the annual directory issue of Water and Pollution Control, (Southam, 1973) and the annual operating summary published by the Ontario Ministry of the Environment (Ontario, 1973). Costs were corrected by an index to bring them up to 1973. The

TABLE 25. SLUDGE HAULAGE COST DATA

Datum No.	Place	Year	Volume (cu.yd.)	Cost ($) (uncorrected)	Unit Cost ($/cu yd) (corrected)		One-way Distance (miles)	% T.S.	Remarks *
(Solid Sludge:)									
1	Preston	'72	6210	10246	1.82		6	24	a
2	Windsor	'72	17600	60148	3.75		13½	37	a
3	S.S. Marie	'69	7526	11300	1.95		13	27	b
4	Ottawa(Bilberry)	'72	728	3484	-		4½	-	c,k,j
5	Ottawa (Green)	'72	10950	11490	1.15		½	30	c
(Liquid Sludge:)						Area(acres)			
1	Belleville	'72	23400	28100	1.33	-	5	-	a
2	Belleville	'69	2927	1760	0.78	0	5	6.4	b,l
3	Brantford	'72	48200	27465	-	-	½	4.3	a,g,j
4	Brantford	'69	33914	12400	-	-	3/4	4.5	b,h,j
5	Brantford	'69	9651	3420	-	-	3/4	19.0	b,h,j
6	Burlington (Sky)	'72	14400	15120	1.15	-	5	-	a
7	Burlington (Sky)	'69	7459	7290	1.27	50	4½	-	b
8	Burlington (Drury)	'72	7200	7560	1.15	-	5	-	a
9	Burlington (Drury)	'69	4868	5210	1.39	50	4	5.7	b
10	Burlington (Eliz)	'72	4800	5040	1.16	-	5	-	a
11	Burlington (Eliz)	'69	6152	6631	1.40	50	3	2.7	b
12	Chatham	'69	8810	8590	1.27	50	10	5.2	b
13	Cobourg	'72	11648	16900	1.60	-	5	-	a
14	Cornwall	'69	1764	2460	1.81	0	7	12.5	b,l
15	Espanola	'69	99	159	2.80	0	5	-	b,l
16	Fergus	'69	4875	4900	1.31	80	2	3.0	b
17	Fort Erie	'69	630	536	1.11	0	5	6.8	b,l
18	Fort Francis	'69	1052	2950	3.65	0	3	8.0	b,l

TABLE 25. (CONT'D)

19	Galt	'72	40000	34000	0.94	-	3	-	a
20	Haileybury	'72	297	500	1.85	-	1	-	a
21	Huntsville	'69	1893	1695	1.16	0	4½	3.7	b,l
22	Kingston	'72	594	1500	2.78	-	20	-	d
23	Kingston twp.	'69	1192	1416	1.54	0	8	4.4	b,l
24	Kitchener	'72	85000	68000	0.88	-	7½	-	a
25	Lakeview	'72	272000	300969	1.22	-	11	-	e
26	Lakeview	'72	300000	150000	0.55	0	¼	-	f,l
27	Midland	'72	520	1040	2.20	-	4	-	a
28	Midland	'69	2970	3830	-	-	3	10.4	b,j
29	Newmarket	'72	128	141	1.21	-	6½	12	a
30	Newmarket	'69	7164	6450	-	-	2	5.5	b,j
31	North Bay	'72	214	263	1.35	0	5	-	a,l
32	North Bay	'69	27051	18610	-	-	8	6.7	b,j
33	Orangeville	'69	1482	2220	1.86	200	5	4.7	b
34	Oshawa	'72	16700	9842	-	-	5	-	a,i,j
35	Owen Sound	'69	8875	8600	1.26	500	5½	8.5	b
36	Point Edward	'69	384	688	2.33	0	5	6.7	b,l
37	Port Colborne	'69	3936	2322	0.77	120	2	3.0	b
38	Preston	'72	6545	5236	0.88	0	6	7.8	a,l
39	Richmond Hill	'72	18000	17600	1.08	-	2¼	-	a
40	Richmond Hill	'69	14758	12900	-	-	2	4.7	b,j
41	Sidney Twp.	'69	168	168	1.30	0	10	4.4	b,l
42	Stratford	'72	16800	16800	1.10	-	7	-	a
43	Thunder Bay (N)	'72	9250	11570	1.38	0	10	-	d,l
44	Thunder Bay (N)	'69	6032	4810	-	-	8	7.0	b,j
45	Thunder Bay (S)	'72	4610	5760	1.38	0	10	-	d,l
46	Thunder Bay (S)	'69	2214	1860	-	-	8	15.5	b,j
47	Tillsonburg	'69	3518	3230	1.19	100	3	2.5	b

TABLE 25. (CONT'D)

48	Timmons	'69	13562	13600	1.30	0	5	5.2	b,1
49	Waterdown	'69	782	1142	1.90	150	7	2.5	b
50	Waterloo	'72	73000	54750	0.82	-	7	-	a

*Remark Codes

a - reported by telephone from plant.

b - reported in excerpt from OWRC report, supplied by Ministry of the Environment (Ont. 71). Although cost is for 1969, distance is for 1970

c - reported by Bill Keay, Regional Municipality of Ottawa-Carleton.

d - reported by letter from plant.

e - reported by K. Sakamoto, Ministry of Environment Project Operations, and 1972 operating report (Ontario, 1973)

f - reported by telephone from Margro.

g - plant owns trucks. Cost includes $4,000 annual depreciation, but capital is probably excluded.

h - plant staff used. Capital costs excluded.

i - plant owns truck. Capital costs probably excluded.

j - datum not used in correlation either because more recent data are available which are similar, or because of a typical cost allocation or equipment.

k - unusual truck used.

l - zero area is shown since sludge was apparently not spread on land.

factors used were 10% for 1972 data and 30% for 1969, corresponding closely to ENR labour cost indices. If a corrected unit cost is not shown, the particular datum was not used for the correlation, for reasons of irregularity as explained in the remarks in the table.

Figures 37 and 38 show the corrected data plotted on linear scales. Figure 38 shows the same data on semi-log scales, where exponential functions appear as straight lines; Figure 40 shows the data on log-log scales, where power functions appear as straight lines. The semi-log and log-log tranformations are useful to reveal exponential and power function correlations which might not be suspected from the untransformed data. It can be seen from Figures 39 and 40 that such non-linear correlations of some significance do exist, even for the liquid sludge data which appear to have no significant correlation on linear scales. On Figures 37 and 38 the non-linear curve fits are shown, along with a linear curve fit and a proportional (i.e. linear through the origin) curve fit. All the curves in these figures were fitted by eye. For the solid sludge data these curve fits are trivial; but for the liquid sludge data, which are very scattered, it should be pointed out that some data points were given more weight than others, according to the size of contract they represented and the scarcity of points for the distance they represented. This was done because a large contract is less likely to have an abnormal cost than a small contract, and because in distance intervals with fewer points it is less likely that outlying points occur. For example, in Figure 38 for liquid sludge, point number 15, an extreme outlier, is the only point representing a contract of less than 100 cubic yards per year, so it was given little weight. Similarly, point number 18 was not very significant; whereas point number 22, at 20 miles, was given a lot of weight since it was the only datum with a distance of more than 11 miles.

Rigorous least-squares linear curve fits were calculated using a standard computer program*. In these calculations, the data points were not weighted according to the scarcity of points in a given distance

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* The on-line program MLREGR in the IBM 360/75 computing system at the University of Waterloo computing centre.

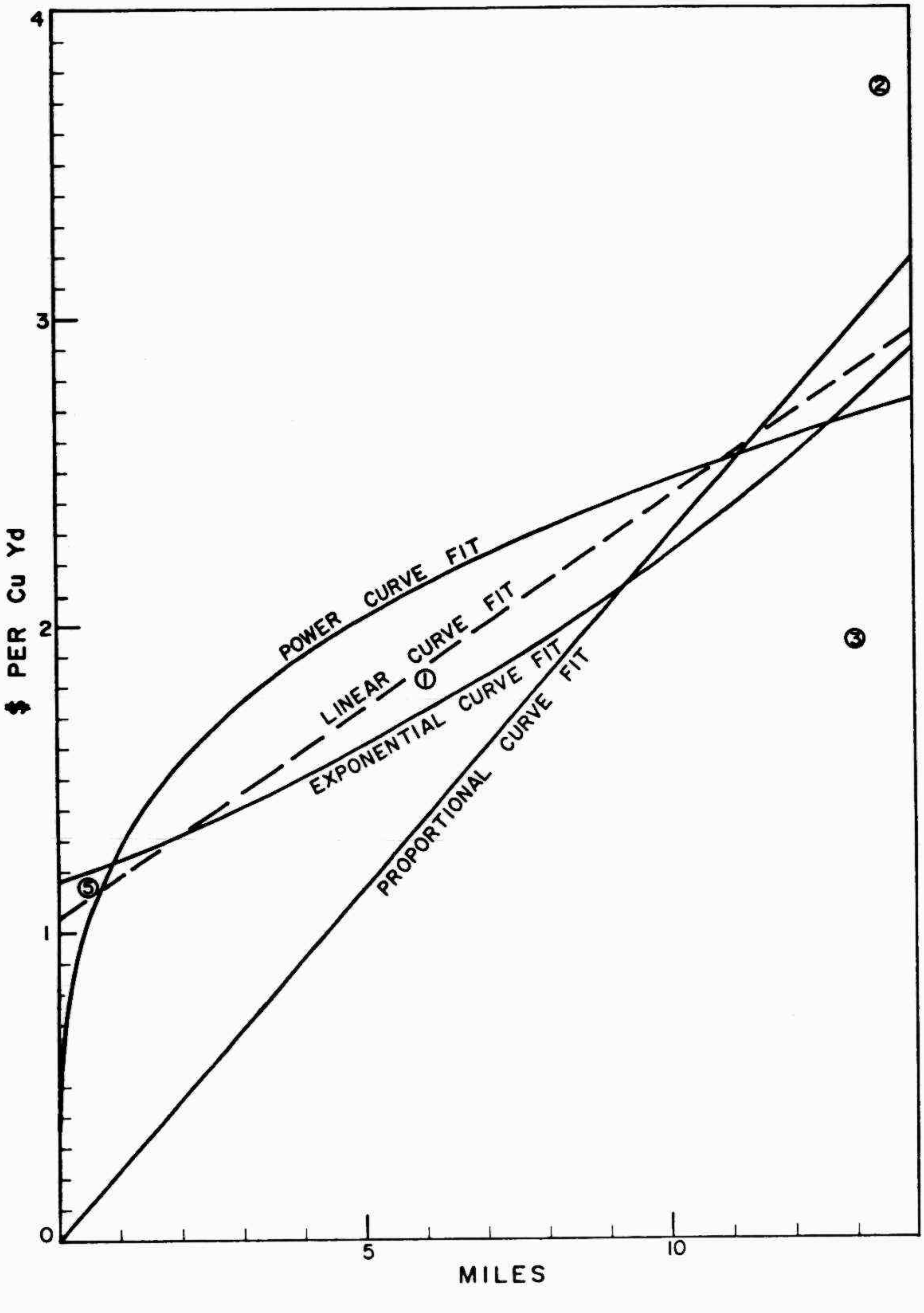


FIGURE 37. PLOTTED DATA AND CORRELATIONS FOR SOLID SLUDGE TRANSPORT COST

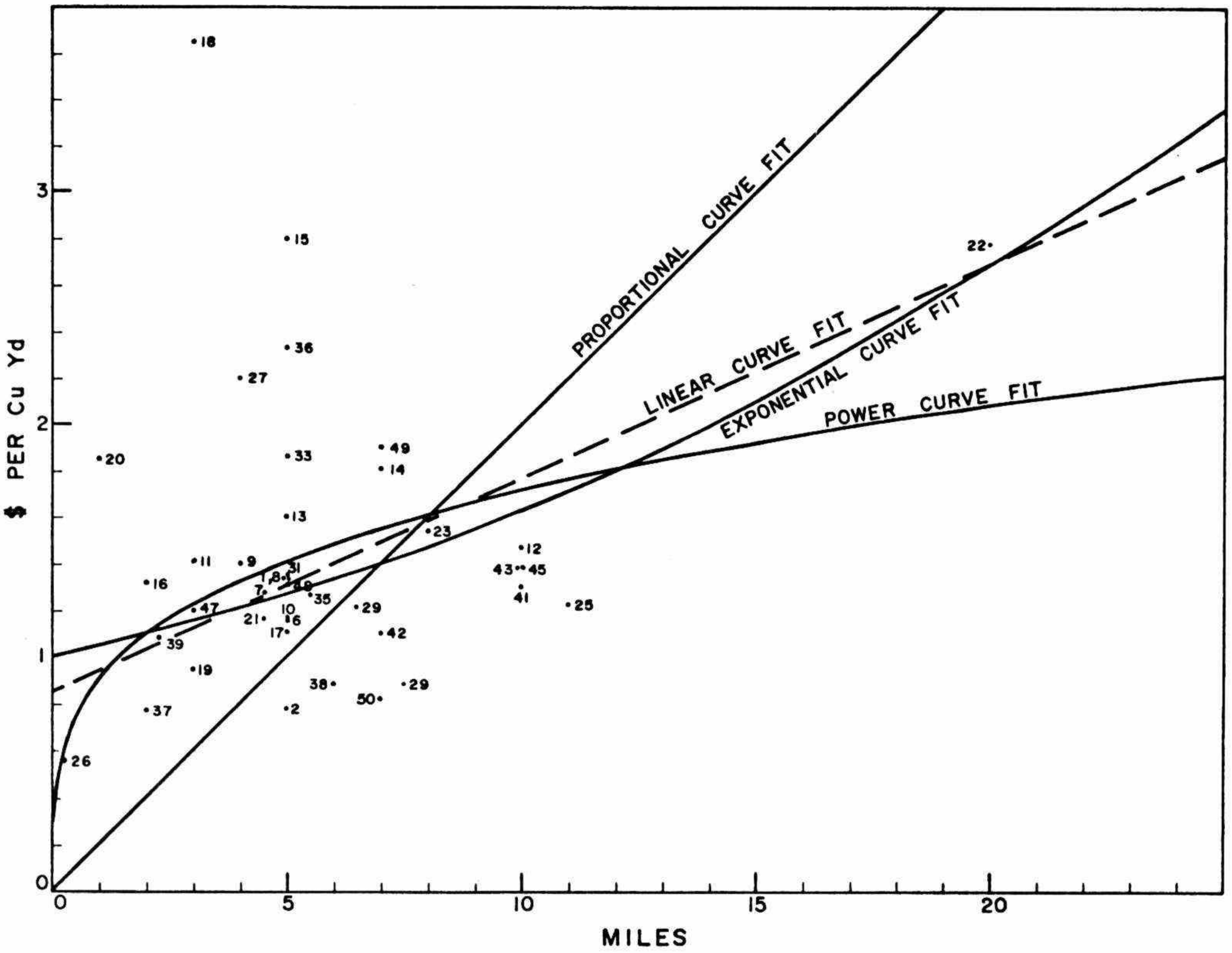


FIGURE 38. PLOTTED DATA AND CORRELATIONS FOR LIQUID SLUDGE TRANSPORT COST

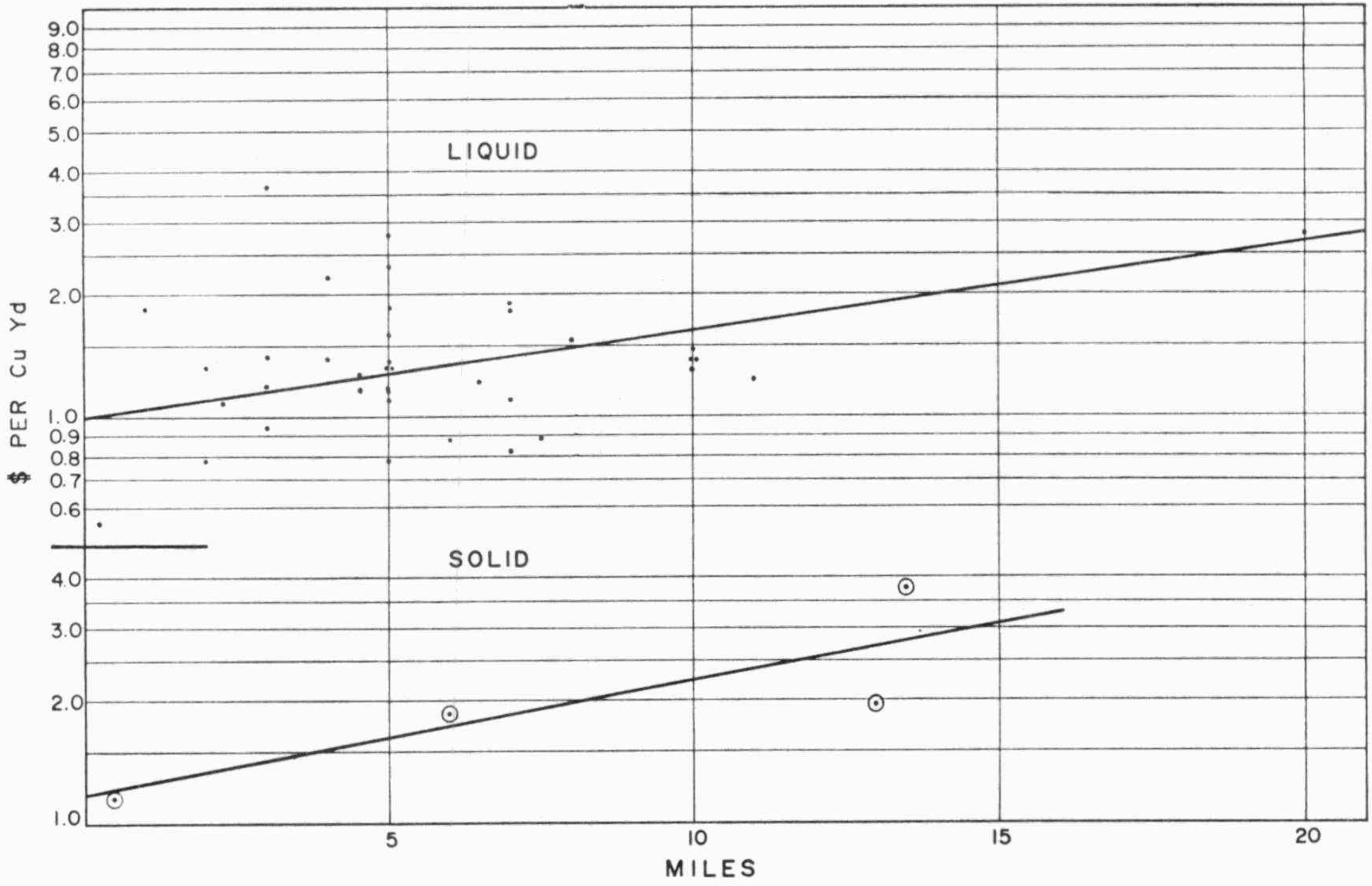


FIGURE 39. EXPONENTIAL CURVE CORRELATIONS FOR TRANSPORT COST DATA

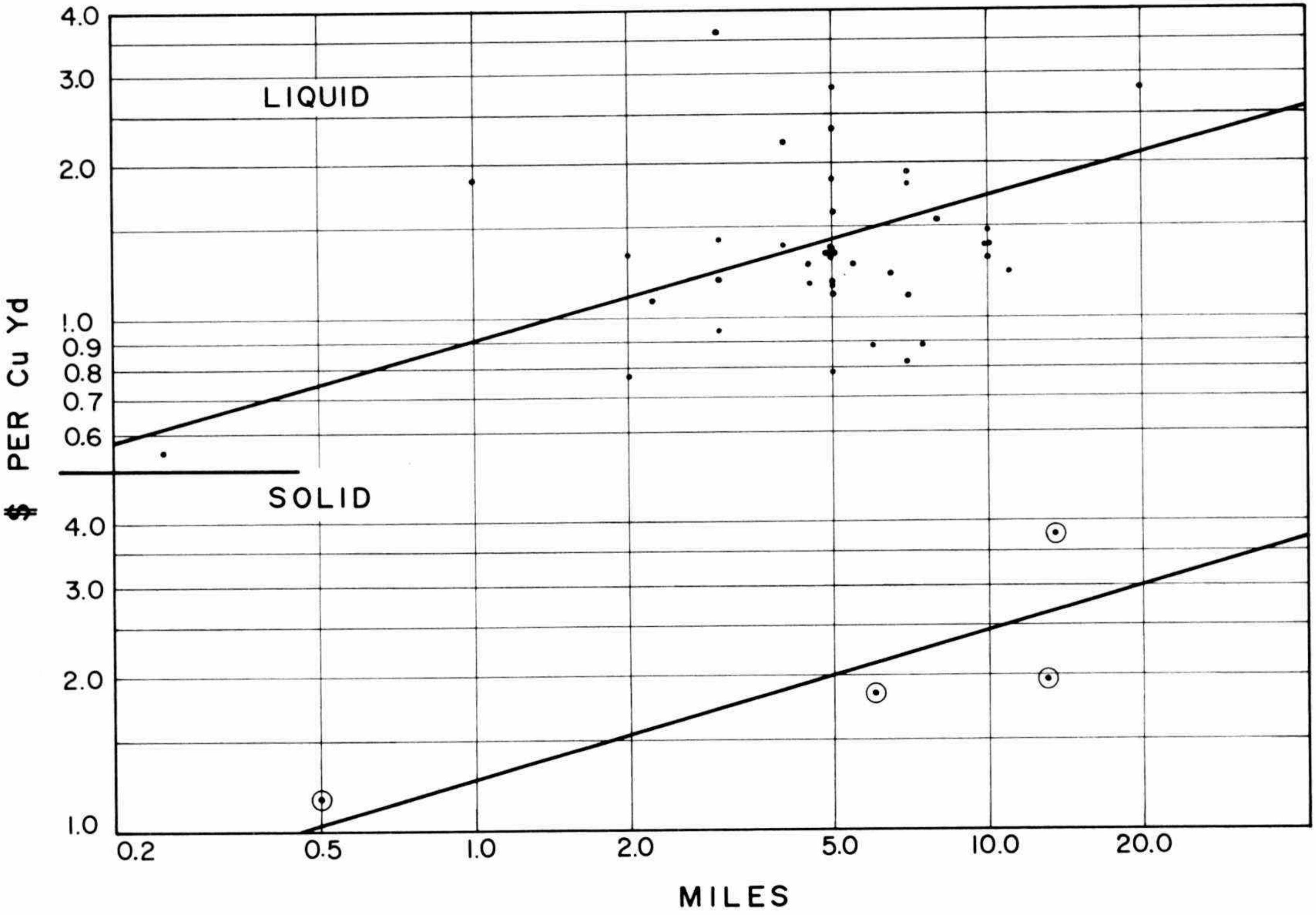


FIGURE 40. POWER CURVE CORRELATIONS FOR TRANSPORT COST DATA

interval, but only according to the size of contract. The amount of weight used increased with sludge volume at a rate that decreased gradually as sludge volume increased, so that all data points with over 70,000 cu/yd received the same weight, ten times as much as a point with only 1000 cu/yd. Some correlations were made which included the variables of solids concentration and spreading area (where applicable). In order to include, in these correlations, the partial information offered by points for which values of these additional variables were not given, such points had values estimated for them by a least-squares technique from points for which values were given.

The resulting correlations are listed in Table 26. Those of direct use in the computer program ALL02 are those with unit cost (C/Q) versus distance (D) alone. The coefficients in these two rigorously calculated correlations for solids and liquid, respectively, are very close to those estimated by eye from the plotted points in Figures 37 and 38 for the linear curve fits. However, the rigorous calculation yields the "standard error" and the "correlation coefficient" for each calculation, thus quantifying the quality of the correlation. The standard error measures the average deviation of the fitted curve from the data; the correlation coefficient measures the significance of the slope of the fitted curve.

The inclusion of the variables, solids concentration and spreading area (where applicable), apparently improves the correlations for unit cost very much; but there is a problem in interpreting the resulting coefficients, which are sometimes negative and sometimes positive, in the correlation itself. Again, in the correlations for total cost, although they seem alright from their standard errors and correlation coefficients, the great variability of the coefficients in the correlation suggest that the correlations cannot be trusted. How could a cost function have a fixed cost (the first coefficient in these correlations) that differs by a factor of five or more for different types of sludge? Or a marginal cost, for distance, that differs by a factor of five depending on whether the sludge will be spread on land or not? And how could negative coefficients be rationalized theoretically?

TABLE 26. CURVE FITS FOR TRANSPORT COST DATA

UNIT COST	STANDARD ERROR	CORREL COEF
SOLID SLUDGE		
$C/Q = +1.0081 + 0.1527D$	0.673	0.804
$C/Q = -2.3366 + 0.1101D + 0.1209S$	0.365	0.950
LIQUID SLUDGE		
$C/Q = +0.9253 + 0.0592D$	0.479	0.436
for data only for sludge spread on land: $C/Q = +1.2308 + 0.0725D - 0.1044S + 0.0011A$	0.352	0.654
for data only for sludge not spread on land: $C/Q = +0.3149 + 0.0140D + 0.1545S$	0.642	0.491
TOTAL COST		
SOLID SLUDGE		
$C = +138316 + 14.438Q + 1841.42D - 9489.8S$	153	0.9
LIQUID SLUDGE		
spread on land: $C = +10702.2 + 1.1481Q + 1428.18D - 4053.9S + 16.200A$	4234	0.9
not spread on land: $C = +4581 + 0.5394Q + 237.100D - 338.23S$	3372	0.9

Notes: C = cost in dollars
Q = quantity in cu/yd
D = one-way distance in miles
S = sludge total solids concentration, % by weight
A = spreading area in acres

It is clear that the correlations could not reliably predict costs in all circumstances. The explanation for the inadequacy of the data probably lies in the local circumstances of each contract. Not only do sludge contractors allocate their costs in different ways, but the responsibility they undertake to find and manage disposal sites varies greatly. That is, if the destination is a land spreading site or landfill, part of the cost of the disposal facility may be passed into transport, especially if the facility is run by the sludge contractor or if the cost data that we collect originate from the plant where the sludge is picked up, where records might not keep ultimate disposal cost separate from haulage cost. In addition, a monopolistic factor sometimes affects transport costs.

Fortunately, the correlations of unit cost versus distance are the most sensible-looking of the lot: they can probably give a quite realistic representation of the dependence of unit cost on distance under normal circumstances.

III.3 Facility Capital Costs

Because of the wide range of local circumstances, it is very difficult to fit cost information from existing facilities into a useful correlation. The costs available sometimes include buildings and grounds, auxiliary equipment such as pumps and maintenance equipment, or they may not. Sometimes the size of the facility is based on capacity for continuous operating and sometimes not. However, some studies exist which have produced correlations of cost with facility size by the painstaking process of calculating engineering estimates for several different sizes of each type of facility. Such a study was reported in 1971 by Black and Veatch Consulting Engineers for the U.S. Environmental Protection Agency (Patterson and Banker, 1971). Assuming that local circumstances are most conservative, that is, there is no way in which costs can be cut, they have produced curves of capital cost, as well as operating and maintenance costs, versus facility size for most of the types of sludge facilities we are concerned with. These will be referred to here as the Black and Veatch (B & V) curves. By finding linear approximations to these curves one can obtain coefficients that yield a dependence of facility costs on size in a quite realistic manner for normal circumstances. It must be borne in mind, though, that actual local circumstances could yield a cost 50% different from that calculated from a B & V curve.

The adoption of the B & V curves required the addition of the cost of land and mobile eqiupment where this was significant. Therefore land cost was added to the correlation as a marginal unit cost per cu/yd/year for lagoons and drying beds, and the cost of one front-end loader was added to the correlation of capital cost into equivalent annual payments, and the correction of costs to Toronto, 1973, by the ENR construction index. Also, the B & V curves tend to use different units to measure the capacity of each type of facility (sq/ft, lb/hr, etc.), and all these had to be converted to cu yd/yr or cu yd, as appropriate. In addition, Black and Veatch omit land spreading and landfill facilities, so costs for these must be built up from fundamentals.

The assumptions made in order to perform this analysis were as follows:

(1) 1 U.S. dollar = 1 Canadian dollar.

(2) Facility amortization time = 25 years.

(3) Interest rate on facilities and equipment = 7% per annum.

(4) Land value = $50,000/acre (or about $1.15/sq ft). (This may seem rather high, but since the land is to be occupied by a facility for 25 years or more, and the land always rises in value faster than money, such land values as may be typical in the future should be chosen.)

(5) Liquid sludge concentration = 5% dry solids.

(6) Accumulation rate on lagoon bottom = 1/4 ft of 20% sludge per year.

(7) Total depth of a lagoon = 8 ft.

(8) Accumulation rate on drying bed = 5/6 ft of 30% sludge per year. This is equivalent to an application rate of nine applications per year, each 8 inches deep (Imhoff and Fair, 1956).

(9) Drying bed equipment requirement (front-end loader) = 1 unit per facility.

(10) Drying bed equipment cost = \$20,000 per unit of equipment.

(11) Hours of operation for processing plants (vacuum filters, centrifuges, incinerators) = 30 hr/wk, 52 wk/yr.

(12) Vacuum filter yield = 8 lb wet solids/sq ft/hr, density 0.8 tons/cu yd, 25% dry solid (Ontario, 1973).

(13) Centrifuge yield = 23% dry solids.

(14) Incinerator input density = 0.8 ton/cu yd.

(15) Landfill maximum dumping (depth accumulation) rate = 1 yd/yr.

(16) Landfill equipment requirement (tractor-dozer) = 1 unit per 10 acres with maximum dumping rate; minimum of 1 unit per facility.

(17) Landfill equipment capital cost = \$50,000 per unit of equipment.

(18) Land spreading equipment requirement (tractor-tanker) = 1 unit per 200 acres with maximum spreading rate; minimum of 1 unit per four facilities.

(19) Land spread maximum spreading rate = 133 cu/yd/yr per acre (from averaging OWRC 1970 data on landspread size and use).

(20) Land spread equipment capital cost = \$80,000 per unit of equipment.

(21) Land spread, landfill and drying bed equipment life and amortization time = 10 years, salvage value = 0.

(22) Land cost allocated to land spread cost = 0.

All assumptions were based on either concrete data or our interpretation of current practices. The calculations performed to obtain the capital cost functions are summarized below.

1. Factor for converting January 1971 U.S. total construction costs to Toronto, September 1973, construction costs paid in equal annual installments over 25 years at an interest rate of 7% per annum:

$$\frac{\text{ENR Toronto August 1973 Index}}{\text{ENR U.S. January 1971 Index}} \times \begin{array}{l}\text{annual payment on 1 dollar}\\ \text{over 25 years @ 7\%}\end{array}$$

$$= \frac{1800}{1500} \times 0.086 = \underline{0.103}$$

2. Formula relating volume and concentration of sludge at input and output of a water removal process (e.g. settling in lagoons, filtering, centrifuging):

Solids input = Solids output, so

$$Q_I S_I = Q_o S_o \tag{13}$$

where Q_I and Q_o are the sludge input and output, respectively, in terms of weight per unit time, and S_I and S_o are the fraction of solids by weight in sludge input and output, respectively.
Now sludge Volume = Dry Solids Volume + Water Volume, so

$$V_I = \frac{S_I Q_I}{D_S} + \frac{(1 - S_I)\, Q_I}{D_W} \tag{14}$$

and

$$V_o = \frac{S_o Q_o}{D_S} + \frac{(1 - S_o)\, Q_o}{D_W} \tag{15}$$

where D_S and D_W are density of dry solids and water, respectively, and V_I and V_o are the sludge input and output, respectively, in terms of volume per unit time. Divide (15) by (14) to obtain

$$\frac{V_o}{V_I} = \frac{S_o Q_o D_W + (1 - S_o)\, Q_o D_S}{S_I Q_I D_W + (1 - S_I)\, Q_I D_S} \tag{16}$$

or

$$\frac{V_o}{V_I} = \frac{S_o Q_o}{S_I Q_I} \cdot \frac{\dfrac{D_W}{D_S} + \dfrac{1 - S_o}{S_o}}{\dfrac{D_W}{D_S} + \dfrac{1 - S_I}{S_I}} . \tag{17}$$

From (13) we have $\frac{S_o Q_o}{S_I Q_I} = 1.$

If we may make the reasonable assumption that

$$\frac{D_W}{D_S} << \frac{1 - S_o}{S_o} \quad \text{and} \quad \frac{D_W}{D_S} << \frac{1 - S_I}{S_I} , \tag{18}$$

then we have a good approximation

$$\frac{V_o}{V_I} = \frac{S_I(1 - S_o)}{S_o(1 - S_I)} ; \tag{19}$$

otherwise $\frac{D_W}{D_S}$ may be approximated by some likely number, such as 1, in which case we have

$$\frac{V_o}{V_I} = \frac{(S_o + 1-S_o)/S_o}{(S_I + 1-S_I)/S_I} = \frac{S_I}{S_o} . \tag{20}$$

3. Lagoon Area Requirement and land cost:

   Conversion from sludge volume input. Assumed accumulation rate on lagoon bottom is 1/4 ft/yr of sludge, 20% dry solids. Thus, lagoon output is effectively 1/4 cu ft/yr per square foot of lagoon area, or 1/108 cu/yd/yr per square foot of lagoon area. Assumed concentration of sludge input is 5% dry solids. Thus, sludge input is $\frac{1}{108}$ x $\frac{20 \times 95}{5 \times 80}$ cu yd/yr per sq ft. That is, area of lagoon is $\frac{108 \times 5 \times 80}{20 \times 95}$ = 22.74 sq ft per cu yd/yr of sludge input. Assumed land cost is $50,000/acre = $1.15/sq ft, which requires yearly payment of $0.099/ sq ft over 25 years at 7% interest. Thus, yearly cost of land for lagoon is $0.099 x 22.74 = $2.25 per cu yd/yr of sludge input.

4. Lagoon Capacity:

   Conversion from lagoon volume to sludge volume input.

   From above, sludge input is 1/22.74 cu yd/yr per square foot of lagoon area.

   Assumed lagoon depth is 8 ft.

   Thus sludge input is $\frac{1}{22.74 \times 8}$ = 0.0055 cu yd/yr per cubic foot of lagoon volume.

5. Drying Bed Area Requirement and land cost:

   Conversion from sludge volume input. Assumed application rate is nine applications per year, each of depth 8 inches. Thus, input is effectively 9 x 3/4 = 6.75 cu ft/yr per sq ft of area, or 1/4 cu yd/yr per sq ft of area. That is, 4 sq ft are required per cu yd/yr of sludge input. Drying bed land cost is $0.099/sq ft yearly, as for lagoon land cost. Thus, yearly drying bed land cost is \$0.099 x 4 = \$0.395 per cu yd/yr of sludge input.

6. Drying Bed Mobile Equipment Cost:
   Assumed requirement is one front-end loader per facility at a cost of \$20,000 spread over 10 years at 7% interest. Annual payment on \$1 over 10 years at 7% is \$0.142. Thus, annual cost of equipment is \$0.142 x 20,000 = \$2,840.
7. Vacuum Filter Capacity:
   Conversion from area to sludge volume input.
   Assumed hours of operation is 30 hr/wk, 52 wk/yr or 1560 hr/yr. Assumed filter yield is 8 lb wet sludge/sq ft/hr, so 8 x 1560 = 12480 lb wet sludge/sq ft/yr. Assumed density of filter output is 0.8 tons/cu yd, so output is $\frac{12480}{2000 \times 0.8} = 7.8$ cu yd/sq ft/yr.
   Assumed concentrations of input and output are 5% and 25% of dry solids, respectively, so filter input is $7.8 \times \frac{25 \times 95}{5 \times 75} = 49.4$ cu yd/yr per sq ft.
8. Centrifuge Capacity:
   Conversion from USGPM to sludge volume input. Assumed hours of operation is 30 hr/wk, 52 wk/yr or 93600 min/yr.
   There are 202 USG per cu yd, so we have $\frac{93600}{202} = 463$ cu yd/yr per USGPM.
9. Incinerator Capacity:
   Conversion from lb/hr sludge volume input. Assumed hours of operation is 30 hr/wk, 52 wk/yr, or 1560 hr/yr.
   Assumed input density is 0.8 ton/cu yd.
   Thus sludge input is $\frac{1560}{2000 \times 0.8} = 0.975$ cu yd/yr per lb/hr.
10. Landfill Area Requirement and Land Cost:
    Conversion from volume input. Assumed dumping (depth accumulation) rate is 1 yd/yr. Thus, 9 sq ft of land is required per cu yd/yr of input. As for all other facilities, land cost is assumed \$0.099/sq ft yearly. Thus, annual landfill land cost is \$0.099 x 9 = \$0.891 per cu yd/yr of input.
11. Landfill Mobile Equipment Requirement and Cost:
    Assumed requirement is 1 unit per 10 acres at dumping rate of 1 yd/yr, with minimum of 1 unit per facility. This means a fixed

requirement of 1 unit plus a variable requirement of 1 unit per 48400 cu yd/yr input.

Assumed equipment cost is $50,000, spread over 10 years at 7% which yields an annual payment of $7100 per unit. Thus, there is an annaul fixed charge of $7100, plus an annual variable cost of $\frac{\$7100}{48400}$ = $0.147 per cu yd/yr of input.

12. Land Spreading Mobile Equipment Requirement and Cost:

    Assumed requirement is 1 unit per 200 acres with spreading rate of 133 cu yd/yr per acre, with a minimum of 1 unit per four facilities. This means a fixed requirement of 1/4 unit, plus a variable requirement of 1 unit per 26600 cu yd/yr of input. Assumed equipment cost is $80,000 per unit, spread over 10 years at 7% which yields an annual payment of $11360 per unit. Thus, there is an annual fixed charge of $\frac{11360}{4}$ = $2840, plus an annual variable cost of $\frac{11360}{26600}$ = $0.426 per cu yd/yr of input.

13. Land Spreading Rate Data and Analysis:

    Data for 1970 from excerpt of OWRC report supplied by Ministry of Environment (Ontario, 1971)

Place	Area (acres)	Volume spread during the year (cu yd)	cu yd per acre
Midland	10	3000	300
Fergus	80	5000	63
Owen Sound	500	9000	18
North Bay	75	200	3
Burlington and Waterdown	150	9600	64
Orangeville	200	1500	8
Chatham	50	10000	200
Port Colborne	120	4000	33
South Peel	1500	300000	200
Tillsonburg	100	4000	40
Richmond Hill	50	18000	360
TOTAL	2835	378000	

Thus, average spreading rate is $\frac{378000}{2835}$ = 133 cu yd/acre/yr.

Figures 41 to 46 show the Black and Veatch curves for construction costs converted to our time and units, and the fixed-charge linear curves we used to approximate them. It can be seen that fixed-charge linear curves can approximate the B & V curves quite well.

On several of these graphs some points are shown which represent cost information on actual existing or planned facilities in Ontario. It can be seen that some of these are quite close to the theoretical curve, while others are quite a bit lower. It is clear, therefore, that the local circumstances of each facility and the basis upon which costs are calculated must be taken into account for accurate cost calculations. The set of cost functions we have obtained, however, are internally consistent and sufficiently accurate to use for preliminary runs with the computer program ALLO2. The capital cost coefficients and their breakdown are shown in Table 27.

III.4 Facility Operating and Maintenance Costs

Operating costs include operations and maintenance labour, materials and supplies. Along with annual cost of capital, annual operating and maintenance costs make up the total annual cost. The same situation regarding original data exists here as in the previous section. Therefore, except for landfills and land spreads, just the 1971 Black & Veatch calculations and estimates are used to obtain cost functions. Typical Toronto 1973 wage rates are used to convert annual man-hours into dollars, namely \$3/hour for operations and \$5/hour for maintenance (\$6 for incinerators). The materials and supplies costs of Black and Veatch were brought up to date using the ENR index. Their throughput variables were all converted to cubic yards or cubic yards/year of sludge input. Operating costs are not given for landfills and land spreading so these were built up from fundamentals.

The calculations performed for this analysis will now be summarized.

1. Conversion from weight solids throughput to volume sludge input, for B & V curves for lagoons, drying beds, vacuum filters, and centrifuges: Assumed input concentration is 5% dry solids by weight. Therefore, there are 20 tons sludge input per ton solids throughput.

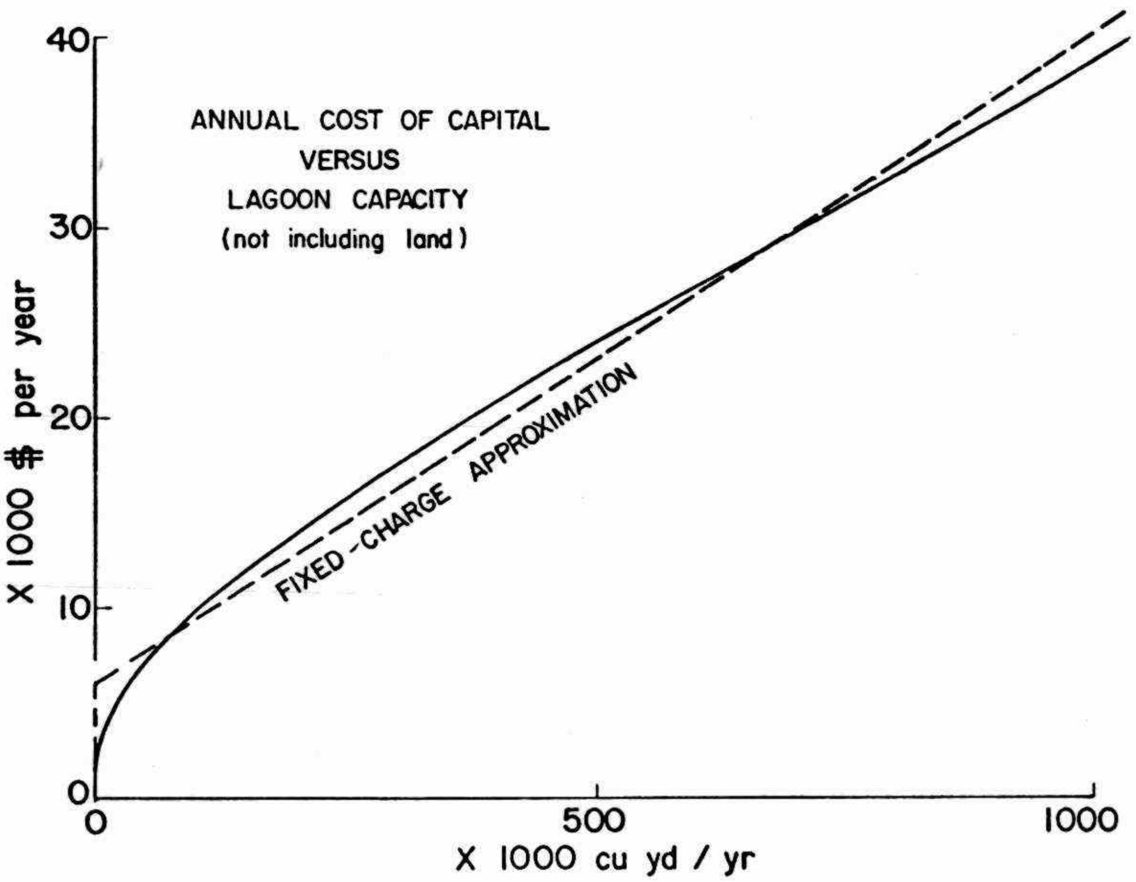


FIGURE 41. ANNUAL COST OF CAPITAL VS. LAGOON CAPACITY

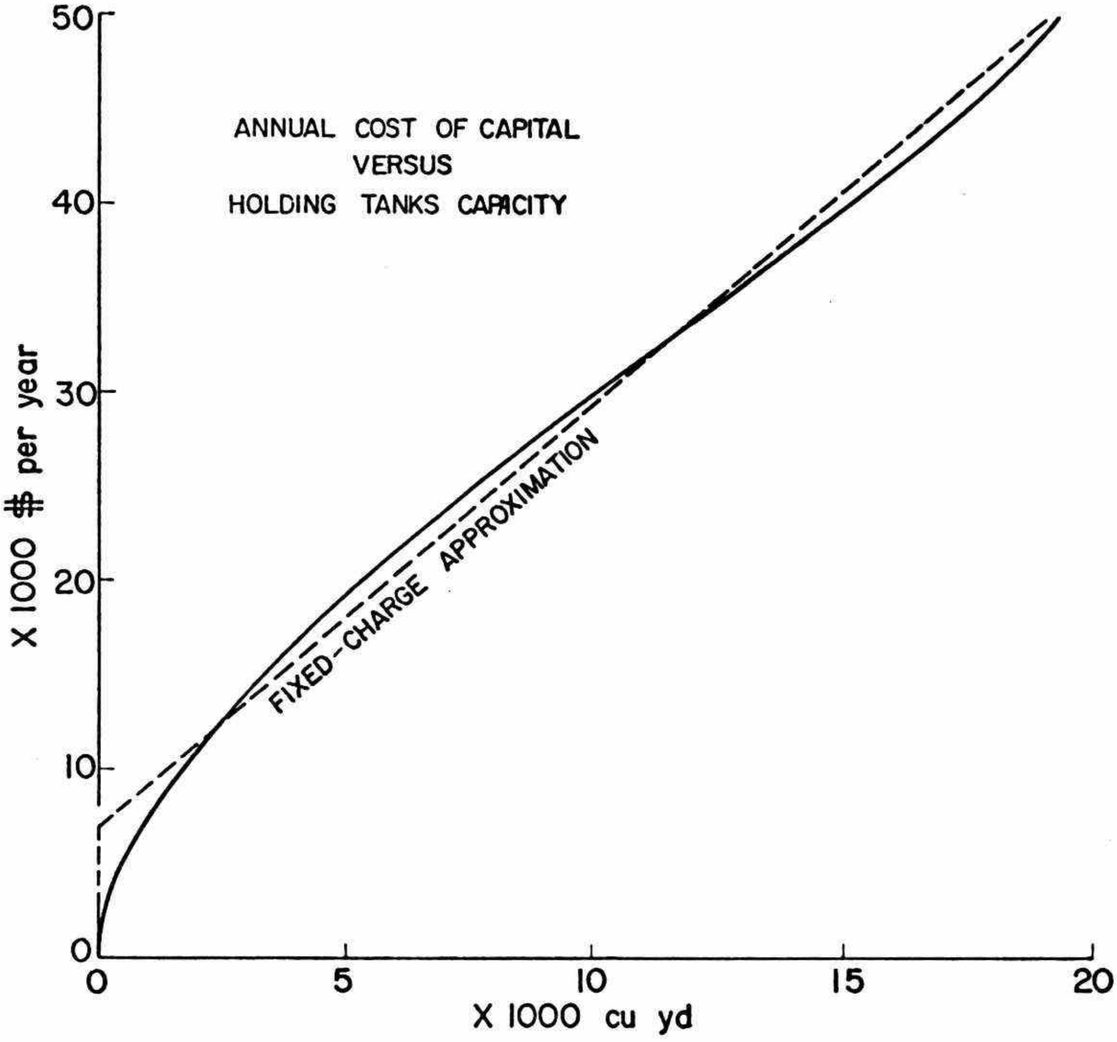


FIGURE 42. ANNUAL COST OF CAPITAL VS. HOLDING TANK CAPACITY

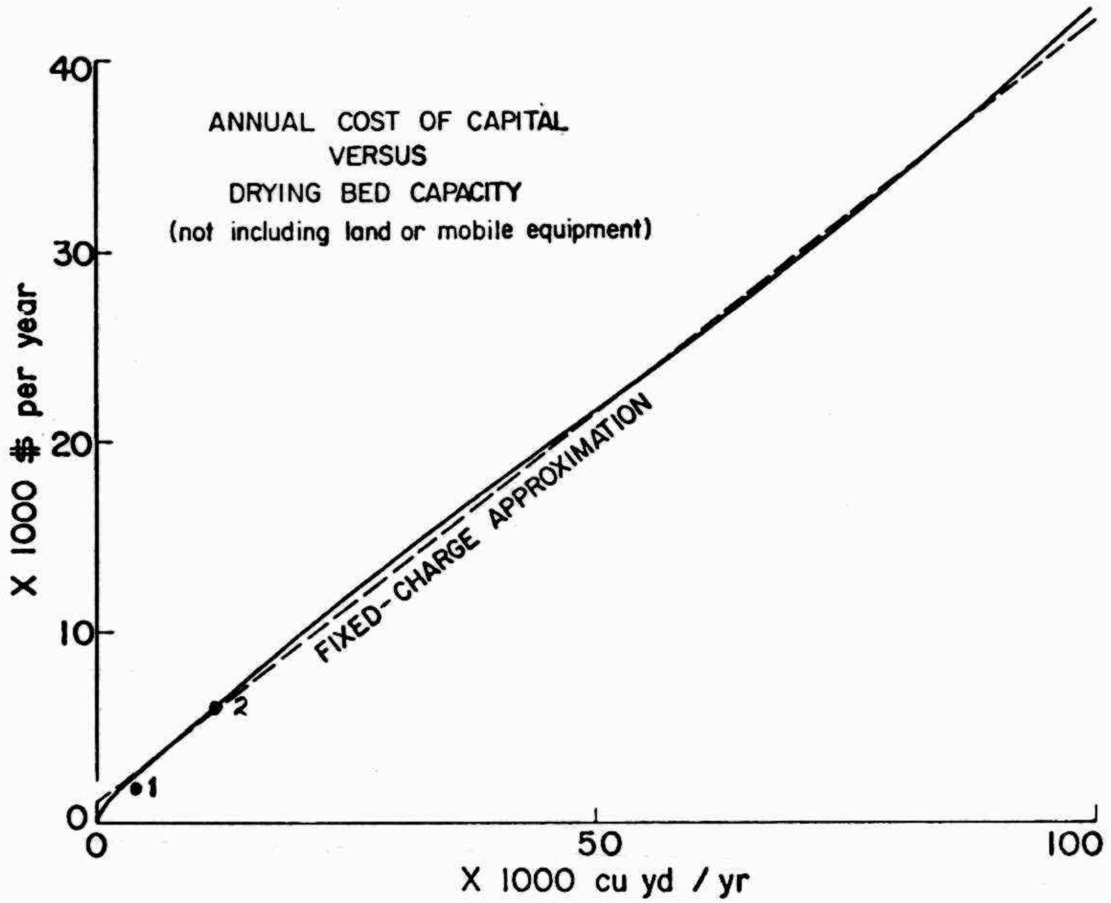


FIGURE 43. ANNUAL COST OF CAPITAL VS. DRYING BED CAPACITY

Note: 1 = Cavan Twp. (Obtained from Ministry of the Environment)

2 = Oshawa (Obtained from City)

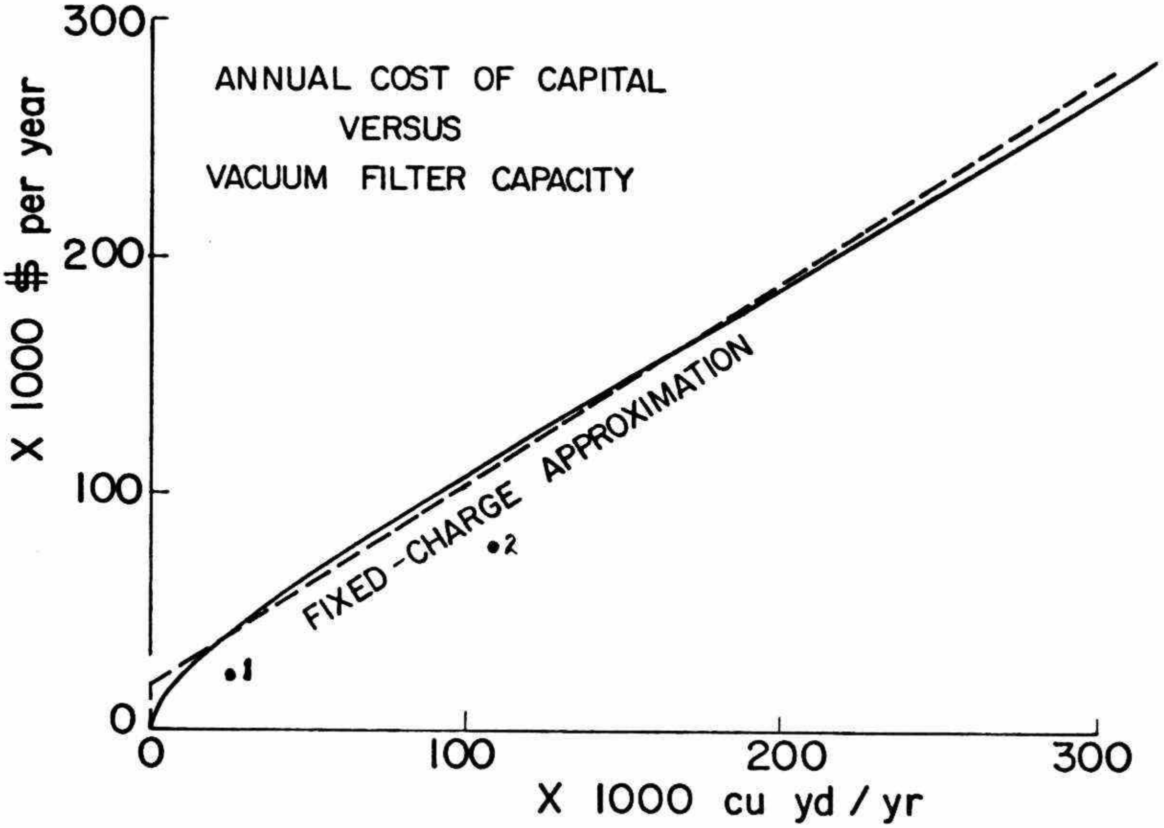


FIGURE 44. ANNUAL COST OF CAPITAL VS. VACUUM FILTER CAPACITY

Notes: 1 = London, Greenway (Obtained from City)

2 = Metro Toronto, Ashbridges Bay (Obtained from Ministry of the Environment)

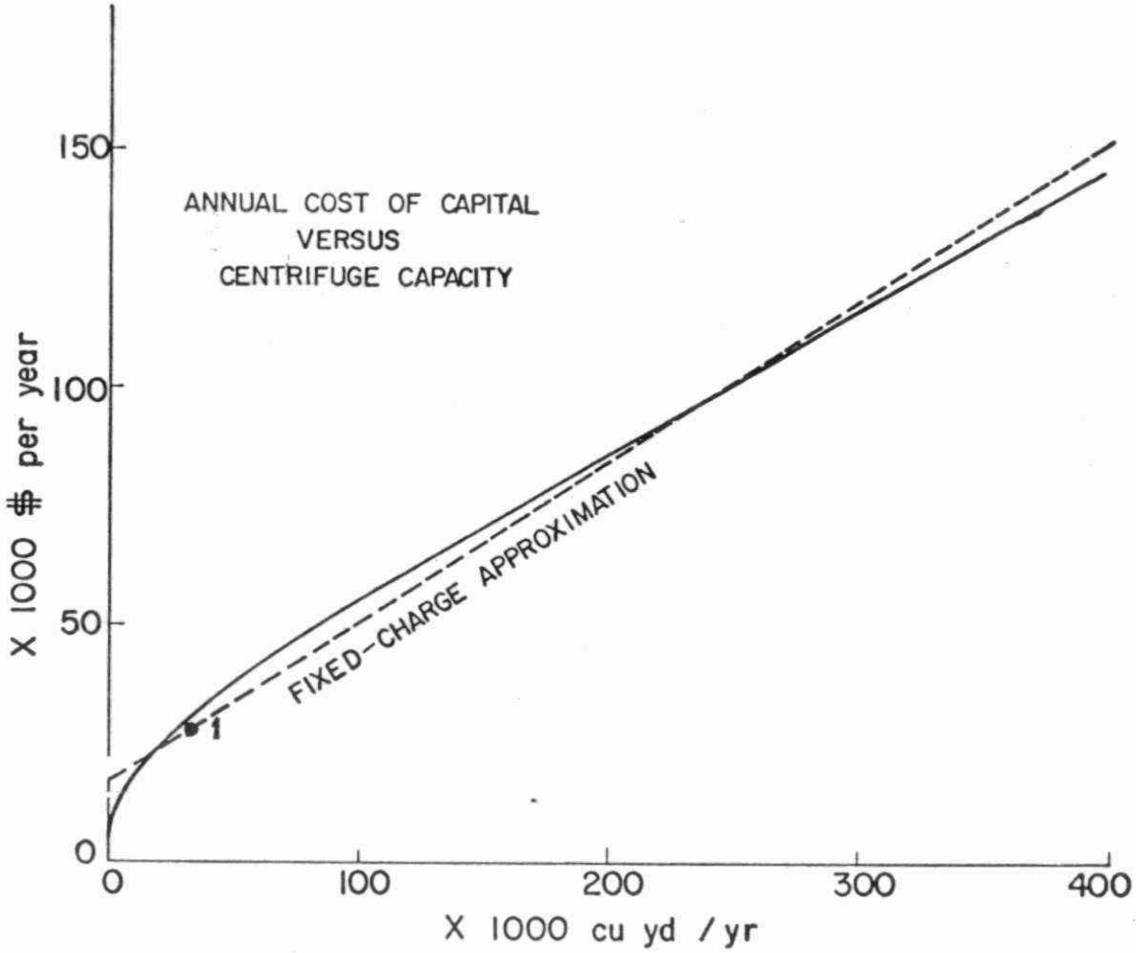


FIGURE 45. ANNUAL COST OF CAPITAL VS. CENTRIFUGE CAPACITY

Note: 1 = Windsor, Little River (Obtained from Ministry of the Environment)

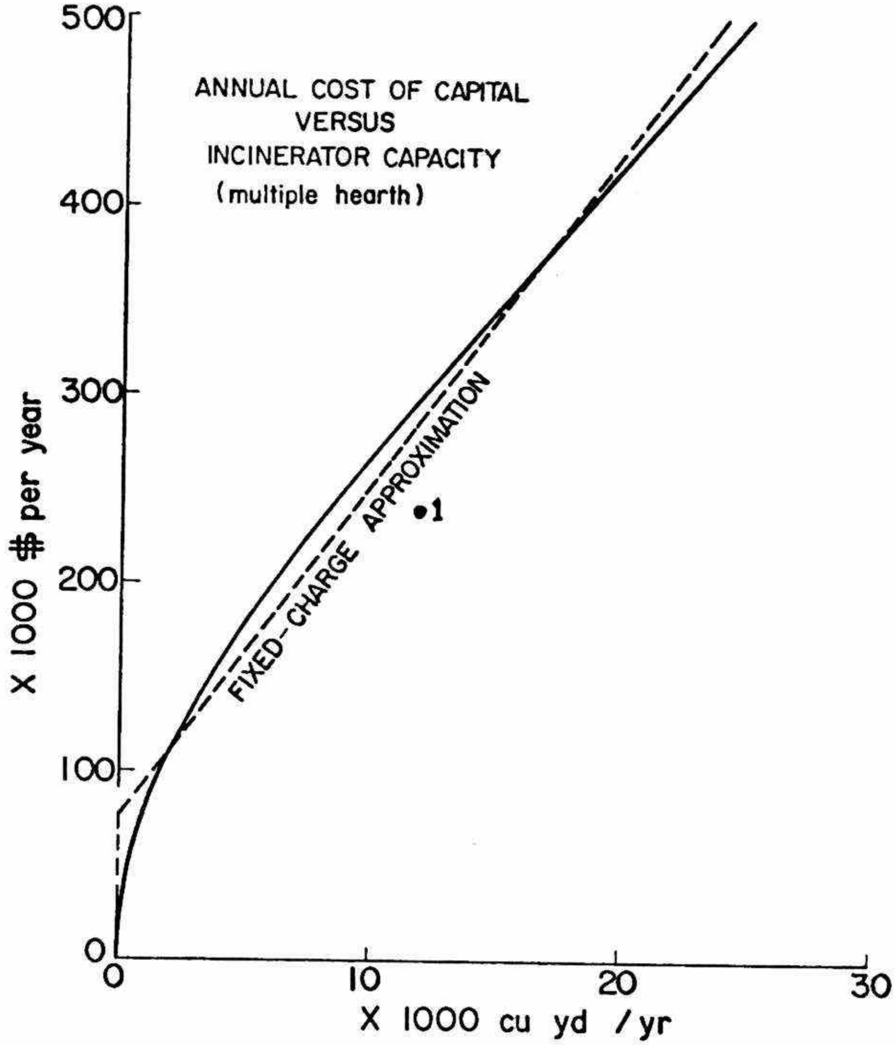


FIGURE 46. ANNUAL COST OF CAPITAL VS. INCINERATOR CAPACITY

Note: 1 = London, Greenway (Obtained from City)

TABLE 27 . ANNUAL COST OF CAPITAL

	(B&V) Construction, Installed Equipment		Mobile Equipment		Land	Total	
	Fixed Charge ($)	Marginal Cost *	Fixed Charge($)	Marginal Cost*	Marginal Cost*	Fixed Charge($)	Marginal Cost*
Lagoon	6000	0.0345	0	0	2.25	6000	2.28
Holding Tank	7000	2.25	0	0	0	7000	2.25
Drying Bed	1160	0.41	2840	0	0.395	4000	0.805
Vacuum Filter	18000	0.856	0	0	0	18000	0.856
Centrifuge	17000	0.337	0	0	0	17000	0.337
Incinerator	75000	17.6	0	0	0	75000	17.6
Landfill	0	0	7100	0.147	0.891	7100	1.038
Landspread	0	0	2840	0.426	0	2840	0.426

* Dollars per cu yd/yr capacity, except for holding tank, which is dollars per cu yd capacity.

Assumed input density is 0.84 tons/cu yd (same as water). Therefore, there are $\frac{20}{0.84}$ = 23.9 cu yd sludge input per ton solids throughput.

2. Conversion from weight solids throughput to volume sludge input for B & V curves for incinerators:

   Assumed input concentration is 25% dry solids. Assumed input density is 0.8 tons/cu yd. Therefore, there are $\frac{4}{0.8}$ = 5 cu yd sludge input per ton solids throughput.

3. Landfill O & M Costs:

   A fixed charge of $5000/yr is assumed for minimal excavations, surveying, etc.

   Balance of operating costs is allocated to mobile equipment (e.g. tractor-dozer or grader) operation man-hours. Assumed that each unit of equipment required by the landfill is operated 40 hr/wk, 50 wk/yr or 2000 hr/yr at union wages for heavy equipment operator, e.g. $8/hr. As for capital costs, operating equipment requirement is 1 unit per 48400 cu yd/yr input. Thus, operating equipment cost is $\frac{2000 \times \$8}{48400}$ = $0.33 per cu yd/yr input.

4. Land spreading O & M Costs:

   Assumed annual fixed charge of $1000 for surveying, inspection and certification.

   Balance of operating cost is allocated to operation of mobile equipment (e.g. tractor-tanker). Assumed that each unit of equipment required by the land spreading is operated 10 hr/wk, 50 wk/yr or 500 hr/yr at union wages for heavy equipment operator, e.g. $8/hr. As for capital costs, operating equipment requirement is 1 unit per 26600 cu yd/yr input. Thus, operating equipment cost is $\frac{500 \times \$8}{26600}$ = $0.151 per cu yd/yr input.

Since the B & V curves are not expected to be accurate in all circumstances, we have not spent any time on graphically fitting straight-line approximations to them. Rather, we have just picked two points from each of them and fitted straight lines to these points. The resulting cost coefficients and their breakdown are shown in Table 28. It appears that costs calculated from these coefficients may deviate from

TABLE 28. ANNUAL OPERATING & MAINTENANCE COST

Coefficients for Fixed-Charge Linear Curves (intersecting B & V curves at two points, if B & V curves are available).

Facility Type; Volume Values at intersection with B & V curve*	Operations Labour Cost		Maintenance Labour Cost		Materials & Supplies Cost		Total Cost	
	Fixed; ($)	Marginal ($/unit*)	Fixed; ($)	Marginal ($/unit*)	Fixed; ($)	Marginal ($/unit*)	Fixed; ($)	Marginal ($/unit*)
Lagoon 240000, 24000	150	0.001	300	0.005	4500	0.232	4950	0.238
Holding Tank 10000, 1000	1700	0.447	900	0.529	1150	0.800	3750	1.776
Drying Bed 24000, 2400	800	0.336	350	0.309	50	0.098	1200	0.743
Vacuum Filter 240000, 24000	4000	0.109	1100	0.033	7600	0.490	12700	0.632
Centrifuge 240000, 24000	3000	0.075	1200	0.033	6500	0.465	10700	0.573
Incinerator 50000, 5000	3900	0.366	3500	0.386	8750	0.513	16150	1.265
Landfill -- --	0	0.330	5000	0.0	0	0.0	5000	0.330
Landspread -- --	0	0.150	1000	0.0	0	0.0	1000	0.150

* Volume units are cu yd /yr of input, except in the case of the holding tank, which is cu yd of inventory.

actual costs by a fair amount, as indicated from the following information obtained from the city of London, Ontario, for 1973:

Facility	cu yd	Actual Cost	Fixed-Charge Linear Curve
Greenway Vacuum Filtration	300,000	$179,800	$202,300
Pottersburg Vacuum Filtration	130,000	87,000	94,900
Greenway Incineration	75,400	210,000	112,000

Thus, it is important to consider local circumstances, where possible, when finding cost coefficients. However, the set of coefficients we have obtained is internally consistent and sufficiently realistic for preliminary runs with the computer program ALL02.

III.5 Processing Plant Parameters: Volume Reduction Ratios

Use of the formula (Eqn. 19) derived in Section III.3 and the assumed input and output concentrations results in the following volume reduction ratios:

Drying bed	0.125
Vacuum Filter	0.160
Centrifuge	0.180
Incinerator	0.25

Since these ratios are entirely theoretical, they are probably slightly optimistic, that is lower than is found in practice.

APPENDIX IV

INPUT DATA FORMAT FOR ALL02

APPENDIX IV

INPUT DATA FORMAT FOR ALLO2

It is necessary to have a good grasp of the discussion in Chapter 6, on the information required by the program, in order to use the following. The first part of this appendix contains a questionnaire that you should use as an aid to organize the information that will be contained in the ALLO2 data deck. The questionnaire is a summary of Chapter 6 specially designed so that by answering it you will automatically put all the information, required in the data deck, into the same order as it will occur in the data deck. This should make coding the data deck a simple matter. The second part of this appendix contains instructions on how to code a data deck by using the completed questionnaire. This coding can be done by anyone who is familiar with FORTRAN I/O formats; this need not be the same person who fills out the questionnaire, although some familiarity with the rest of this manual may be helpful to him.

Sample data decks are shown at the end of this Appendix.

IV.1 How to Use the Questionnaire

The questionnaire is shown as Table 29. Multiple copies should be made of the blank questionnaire so that for each run you can write directly into a blank copy. Additional copies of question 3 will be required for runs that contain more than one case of data. The questionnaire shows question 3 only once, whereas you will need one copy of question 3 for each data case. You may also need to made up larger answer tables if those shown here do not have enough rows or columns for your model.

All you have to do is answer the questions in order, skipping from one part of the questionnaire to another when instructed to do so.

After some of the questions, references are given back to the main chapters of the manual to help you review the proper material in case you have difficulty answering the questions.

TABLE 29. QUESTIONNAIRE FOR EASY CONSTRUCTION OF DATA DECK OF AN ALLO2 RUN

1. Determining General Type of Input

a) Is this run a continuation of a previous run which was abnormally terminated due to violation of time or output volume restrictions? (Yes or No) cf: 5.7.6 ☐

If "no", skip the rest of question 1 and begin question 2.

b) Did the previous run, of which this run is a continuation, complete a data dump which is available for input to this run? (Yes or No) cf: 5.7.6, 6.1, 6.2.7 ☐

If "no" skip the rest of question 1 and begin question 2.

c) What title should go on this data deck? It may consist of up to 80 characters, including blanks. The first 4 characters must be "REST".

____

d) How many combinations of facilities were to be explicitly entered for evaluation in the case of data being run at the time of termination? That is, how was question 3 (n) answered for the terminated case in the previous run? cf: 5.7.3, 6.2.6 ☐

If not zero, go directly from here to question 3 (r) to enter the rest of the facility combinations which the computer would be expecting after the data dump.

e) If you do not want any other cases of data to be included in this run, then skip this question and go directly to question 4.

What comment do you wish to appear in the data deck before the computer reads the title of the next case of data? It may consist of up to 80 characters, including blanks. The first 4 characters must not all be "=".

____

Now skip question 2 and begin question 3.

2. Information to Begin a New Run

a) What title should go on this data deck? It may consist of up to 80 characters, including blanks. The first 4 characters must not be "REST".

____

b) How many sources are in the model for this run? ☐
cf: 5.2, 6.2

c) How many summer dead-end facilities are in the model? ☐
cf: 5.2, 6.2

d) How many all-year intermediate facilities? ☐
cf: 5.2, 6.2

e) How many all-year dead-end facilities? ☐
cf: 5.2, 6.2

f) How many winter intermediate facilities? ☐
cf: 5.2, 6.2

g) What 4 character abbreviated names for the sources do you want in the computer printout? List them here on the solid lines in the order desired for numbering the sources: cf: 6.2

1 ________ . . . .

2 ________ . . . .

3 ________ . . . .

4 ________ . . . .

5 ________ . . . .

6 ________ . . . .

7 ________ . . . .

8 ________ . . . .

9 ________ . . . .

10 ________ . . . .

h) What 4 character abbreviated names for the facilities do you want in the computer printout? List them here on the solid lines in the order desired for numbering the facilities. All summer dead-end facilities must come first, then all all-year intermediate, then all all-year dead-end, and finally all winter intermediate. cf: 6.2

1 ________ . . . .

2 ________ . . . .

3 ________ . . . .

4 ________ . . . .

5 ________ . . . .

6 ________ . . . .

7 ________ . . . .

8 ________ . . . .

9 ________ . . . .

10 ________ . . . .

11 ________ . . . .

12 ________ . . . .

13 ________ . . . .

14 ________ . . . .

15 ________ . . . .

16 ________ . . . .

17 ________ . . . .

18 ________ . . . .

19 ________ . . . .

20 ________ . . . .

21 ________ . . . .

22 ________ . . . .

23 ________ . . . .

24 ________ . . . .

25 ________ . . . .

26 ________ . . . .

27 ________ . . . .

28 ________ . . . .

29 ________ . . . .

30 ________ . . . .

On the right hand dotted lines in (g) and (h) above, comments may be printed which will appear at the beginning of the computer printout along with the abbreviated names. For instance, it may be useful to have the full name of the source or facility appear beside its abbreviation; or comments regarding the type of model used in the run.

i) Will any case of data in this run use trip lengths which the computer will initially calculate from x, y, coordinates for sources and facilities? That is, will the 3rd choice in question 3 (h) be chosen for any case of data in this run? (Yes or No) ☐
cf: 6.2.1, 6.2.5

If "no", then skip the following questions (j) and (k) and go directly to question 2 (1).

j) What number should the computer multiply straight line distances by to estimate trip lengths? ☐
cf: 6.2.1, 6.2.5

k) What x, y coordinates for the sources and facilities should be used to calculate straight line distances between points? List them below, in order corresponding to the numbers assigned in (g) and (h) above.
cf: 6.2.1, 6.2.5

Sources	x	y	Facilities	x	y
1			1		
2			2		
3			3		
4			4		
5			5		
6			6		
7			7		
8			8		
9			9		
10			10		
			11		
			12		
			13		
			14		
			15		
			16		
			17		
			18		
			19		
			20		
			21		
			22		
			23		
			24		
			25		
			26		
			27		
			28		
			29		
			30		

l) What maximum spread in total system cost interests you in the final set of best combinations for each case of data in this run? (That is, the maximum difference between highest and lowest cost.) ☐
cf: 5.7.2, 6.2.2

m) What is the maximum number of near-optimal combinations you want to inspect, that is, how many should be printed in the final set of best combinations for each case of data in this run? ☐
cf: 5.7.2, 6.2.2

3. Information to Begin a New Data Case.
cf: 3.2.6

a) What is the title of this case of data (in 80 characters or less, including blanks)?

____

b) What is the annual production of each source? List in the order of the numbering of the sources. cf: 6.2.3

1 __________ 2 __________ 3 __________ 4 __________

5 __________ 6 __________ 7 __________ 8 __________

9 __________ 10 __________

c) What is the size limit (in terms of input) and the ratio volume out/volume in for each facility? List in the order of the numbering of the facilities. cf: 5.3.1, 5.4, 6.2.3

Facility	Size Limit	Volume Reduction Ratio
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		

d) For each facility, what is the fixed capital cost (intercept on the vertical axis) and the variable capital cost (slope of the line) on a graph showing the increase of annual capital cost with size of the facility? List in the order of the numbering of the facilities.
cf: 5.3, 6.2.3

Facility	Fixed Capital Cost (A_1)	Variable Capital Cost (B_1)
1		
2		
3		
4		
5		
6		
7		
8		

9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		

e) For each facility, what is the fixed operating and maintenance cost (intercept on the vertical axis) and the variable operating and maintenance cost (slope of the line) on a graph showing the increase in annual operating and maintenance cost with the size of the facility? List in the order of the numbering of the facilities.

cf: 5.3, 6.2.3

Facility	Fixed O & M Cost (A_2)	Variable O & M Cost (B_2)
1		
2		
3		

4 ____________________ ____________________

5 ____________________ ____________________

6 ____________________ ____________________

7 ____________________ ____________________

8 ____________________ ____________________

9 ____________________ ____________________

10 ____________________ ____________________

11 ____________________ ____________________

12 ____________________ ____________________

13 ____________________ ____________________

14 ____________________ ____________________

15 ____________________ ____________________

16 ____________________ ____________________

17 ____________________ ____________________

18 ____________________ ____________________

19 ____________________ ____________________

20 ____________________ ____________________

21 ____________________ ____________________

22 ____________________ ____________________

23 ____________________ ____________________

24 ____________________ ____________________

25 ____________________ ____________________

26 ____________________ ____________________

27 ____________________ ____________________

28 ____________________ ____________________

29 ____________________ ____________________

30 ____________________ ____________________

f) Is there any all-year dead-end facility in the model which may be permitted to receive material directly from a source without going through an all-year intermediate facility? (Yes or No)
cf: 6.2.4 ____

g) If there are any summer dead-end facilities, what fraction of the year are these prohibited from use?
cf: 5.2, 6.2.4 ____

h) In this data case, how will the transport data be entered? Check one of the following three alternatives. cf: 6.2.1, 6.2.5

i. Transport cost for each point pair i will be entered directly as cost per unit volume C_i. ____

ii. The computer will be expected to compute cost per unit volume for each point pair i from a formula $a_{j_i} + b_{j_i} d_i$ where j_i and d_i will be entered for each point pair and a's and b's will be entered as haulage formulas preceding all the j's and d's. ____

iii. The computer will be expected to compute cost per unit volume for each point pair i from a formula $a_{k_i} + b_{k_i} t_i$ where ki will be entered for each point pair, t_i is the trip length calculated by the computer from co-ordinates given in question 2(j), and a's and b's will be entered as haulage formulas preceding all k's. ____

i) If the first alternative in (h) above was chosen, then skip this question and go on to question 3(j).

What are the a's and b's of the haulage formulas? List up to nine different formulas. cf: 6.2.1, 6.2.5

Haulage formula 1: a_1 = ____ b_1 = ____
2: a_2 = ____ b_2 = ____
3: a_3 = ____ b_3 = ____
4: a_4 = ____ b_4 = ____
5: a_5 = ____ b_5 = ____
6: a_6 = ____ b_6 = ____
7: a_7 = ____ b_7 = ____
8: a_8 = ____ b_8 = ____
9: a_9 = ____ b_9 = ____

j) What are the values for j,k,c, or d from all sources to all facilities? Fill in the following table, extending it if necessary. If the first alternative in question 3(h) was chosen, ignore the spaces for j_i or k_i. If the 3rd alternative was chosen ignore the spaces for C_i or d_i If the answer to question 3(f) was "no", then any spaces for values from sources to all-year dead-end facilities can be left blank. cf: 6.2.1, 6.2.5

From Source: To Facility	1	2	3	4	5	6
1 j or k C or d						
2 j or k C or d						
3 j or k C or d						
4 j or k C or d						
5 j or k C or d						
6 j or k C or d						
7 j or k C or d						
8 j or k C or d						
9 j or k C or d						
10 j or k C or d						
11 j or k C or d						
12 j or k C or d						
13 j or k C or d						
14 j or k C or d						
15 j or k C or d						
16 j or k C or d						
17 j or k C or d						
18 j or k C or d						

19 j or k C or d						
20 j or k C or d						
21 j or k C or d						
22 j or k C or d						
23 j or k C or d						
24 j or k C or d						
25 j or k C or d						
26 j or k C or d						
27 j or k C or d						
28 j or k C or d						
29 j or k C or d						
30 j or k C or d						

k) Repeat 3(j) for values from all winter intermediate facilities (in order of numbering across the table from left to right) to all summer dead-end facilities (in order of numbering down the side).

From Facility: → To Facility:						
↓ j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						

j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						

1) Repeat 3(j) for values from all all-year intermediate facilities (in order of numbering across the table from left to right) to all all-year dead-end facilities (in order of numbering down the side).

From Facility: →
To Facility:
↓

j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						
j or k C or d						

m) What weight factor is to be used for this data case, in order to bias the optimization of winter distribution for or against the use of winter intermediate facilities (and thus for or against putting demand on summer dead-end facilities)? ☐

cf: 5.6.1, 6.2.3

n) How many combinations of facilities will be explicitly entered in this case of data, implying that the computer must evaluate only these combinations? If none, implying that the computer must evaluate all possible combinations of facilities, then say zero. ☐

cf: 5.7.3, 6.2.6

o) How often, in terms of the enumeration of facility combinations, should the computer print out the optimized distribution for facility combinations which will not necessarily end up in the final set of best combinations? For example, if you say 1, then every facility combination evaluated will have its optimized distribution printed out; if you say 2, then every second facility combination will have its optimized distribution printed out, etc. (Avoid a total of more than about 10 such printouts per data case.) ☐

cf: 5.7.4, 6.2.7

p) How often, in terms of the enumeration of facility combinations, should the computer dump data onto dataset 1W2 in order to permit continuing the run in case it is abnormally terminated due to violation of time or output volume restrictions? (If you say N, the data dump will occur every Nth time a facility combination is evaluated, and a terminated run could be restarted without re-evaluating more than N facility combinations). ☐

cf: 5.7.6, 6.2.7

q) What is the largest total annual cost that the most inexpensive solution in the final set of best solutions could have, as a reliably estimated upper limit? If no such upper bound is reliably known, then leave this space blank. ☐

cf: 6.2.8

r) If question 3(n) was answered "zero", skip these instructions and go on to question 3(s).
What combinations of facilities should the computer evaluate? List them here in the desired order of evaluation. For each combination, first give the number of facilities in the combination, and then list the facilities in the combination by their numbers as assigned in question 2(h). The facility numbers in a combination must be in increasing order. (If this question was arrived at directly from question 1(d), then note that the combinations listed up to the last "data dump completed" statement in the printout of the previous run must not be repeated here - just enter as many combinations as the computer would expect after that point).

cf: 5.7.3, 6.2.6, 5.7.6

How many facilities in combination	Facility numbers
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .
________	. . . .

Now skip questions 3(s), (t), and (u), and go on to 3(v).

s) This question and the following 2 questions, (t) and (u), are to be answered only if 3(n) was answered "zero". What facilities should be included in every combination when the computer generates all possible facility combinations for evaluation? List them here, indicating them by their numbers as assigned in question 2(h). cf: 5.7.5, 6.2.8

___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___

t) What pairs of facilities must **not** occur in any combination when the computer generates all possible facility combinations for evaluation? List them here, indicating them by their numbers as assigned in question 2(h). cf: 5.7.5, 6.2.8

__________ and __________ must not both occur in the same combination

__________ " __________ "

__________ " __________ "

__________ " __________ "

__________ " __________ "

__________ " __________ "

__________ " __________ "

__________ " __________ "

__________ " __________ "

__________ " __________ "

u) How many facilities of each kind, as an upper limit, are worth looking at in a combination when the computer generates all possible facility combinations for evaluation? cf: 5.7.5, 6.2.8

Summer dead-end __________

All-year intermediate __________

All-year dead-end __________

Winter intermediate __________

v) If this is the last case of data to be included in this run, skip this question and go on to question 4.

What comment do you want to appear in the data deck at the end of this case of data? It may consist of up to 80 characters, including blanks. The first 4 characters must not all be "=".

____

Now begin question 3 again so as to fill out the data for the next case in this run.

4. End of Run

a) What comment do you want to appear in the data deck at the end of the last case of data? It may consist of up to 80 characters, including blanks. The first 4 characters must be "====".

____

END OF QUESTIONNAIRE

IV.2 How to Code the ALLO2 Data Deck

First, you should be aware of the general structure of the data deck, which will be one of the two types illustrated in Figure 47. This shows that the data deck consists of several smaller decks, whose more detailed structures are illustrated in Figures 48 through 51.

The choice of the overall configuration of the data deck is made in the questionnaire in question 1(a) and (b). If either of these questions is answered "no", then the normal configuration (see Figure 47 (a)) is chosen; they must both be answered "yes" for the configuration in Figure 47 (b) to be chosen, which we will refer to as the "restart configuration".

IV.2.1 Normal Configuration

Refer to Figure 47(a). The title card of the data deck comes from question 2 of the questionnaire, along with the ALLO2 Start Deck. Each case Start Deck and Case End card comes from a completed copy of question 3. The Run End card comes from question 4. Note that if there is only one case in the run, there will be no Case End card, only a Run End card. The details of the formats are shown in Table 30. For each card or group of cards the table shows the format in its left-hand column and the method of obtaining entries from the questionnaire is shown in the righthand column.

The formats are first described in terms of the number of cards required and the types of data fields on the cards. Then the FORTRAN format statement is given, as it actually occurs in the computer program, so that you can see the exact order and size of the data fields. For programming efficiency, some of the format statements are re-used in several places, with the result that sometimes data will not be read from all of the field which a format statement defines on a card. Since some computer systems perform data checks on each whole card before determining which of its fields are actually going to be used, it is good policy to leave unused fields blank. Avoid putting card labels or comments in unused fields, unless they consist of characters compatible with the data field type. Most of the formats include several "non-data" fields of type X which are intended to contain any card labels or comments.

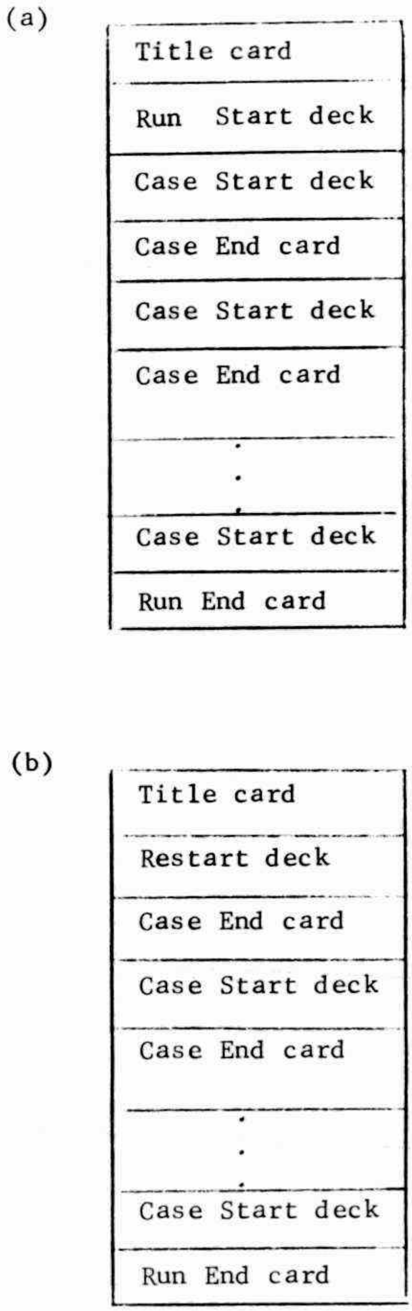


FIGURE 47. OVERALL CONFIGURATION OF DATA DECKS

(a) Normal Configuration
(b) Configuration with First Characters of Title Card = "REST"

(a)

Number of sources and numbers of facilities of each kind
Source name cards
Facility name cards
Travelling factor ALPHA
Source Coordinate cards
Facility coordinate cards
Solution storage criteria

Leave out if ALPHA less than 0.0001

(b)

Title card
Source production cards
Facility characteristic cards
Indicator to permit all-year dead-end facilities to receive directly from sources; and the fraction WINTER
Transport data mode I
Haulage formula cards
Transport data deck
Weight factor
IDEFIN, ARBOUT, IDUMP, C*
IDEF deck (if IDEFIN greater than zero) or COMBEX deck (if IDEFIN = 0)

Leave out if I = "ICST"

FIGURE 48. CONFIGURATIONS OF START CARD DECKS

(a) Run Start
(b) Case Start

(a) For I = "IDST"

Haulage formula indicators with 1st facility as destination

Trip lengths with 1st facility as destination

Haulage formula indicators with 2nd facility as destination

Trip lengths with 2nd facility as destination

.
.
.

(b) For I = ICST"

Unit transport costs with 1st facility as destination

Unit transport costs with 2nd facility as destination

.
.
.

(c) Neither of the above

Haulage formula indicators with 1st facility as destination

Haulage formula indicators with 2nd facility as destination

.
.
.

(d) Data from all sources to all facilities

Data from winter intermediate facilities to summer dead-end facilities

Data from all-year intermediate facilities to all-year dead-end facilities

FIGURE 49. CONFIGURATION OF TRANSPORT DATA DECK
(a), (b), (c), for the 3 Different Modes of Transport data;
(d) Overall Grouping of Data

1st facility combination
2nd facility combination
3rd facility combination
.
.
.
IDEFIN th facility combination

FIGURE 50. IDEF CARD DECK

Inclusion cards
Inclusion end card
Exclusion cards
Exclusion end card
MAXSIZ card

FIGURE 51. COMBEX CARD DECK

TABLE 30. DATA FORMATS: NORMAL CONFIGURATION
(see Figure 47 (a))

TITLE CARD

One card containing 20 alphameric fields of 4 characters each. Format (20A4).	Use the answer to question 2(a). Be sure the first 4 characters on the card are not "REST"

RUN START DECK
(see Figure 48 (a))

1. Number of sources and numbers of facilities of each kind

One card containing 5 integer fields. Format (5(7X,I3)).	Use the answers to question 2(b), (c), (d), (e) and (f) in that order.

2. Source name cards

Number of cards equal to NS = the answer to question 2(b), each card containing one integer field and 19 alphameric fields. Format (I2,2X,19A4).	Use one line of the answer to question 2(g) per card, with the line number in the integer field, the characters on the solid line in the first alphameric field, and the characters on the dotted line in the other 18 fields.

3. Facility name cards

Number of cards equal to NF = the sum of the answers to questions 2(c), (d), (e) and (f), each card coded the same way as for source name cards.	Use one line of the answer to question 2(h) per card.

4. Travelling factor ALPHA

One card containing 7 real number fields, of which only the first one is used. Format (10X,7F10.6).	Leave blank or zero if question 2(i) is answered "no"; otherwise enter the answer to question 2(j). In the latter case be sure the number is at least 0.0001.

5. Source Coordinate cards
(Leave out if ALPHA is blank or less than 0.0001)

Number of cards equal to NS, each card containing 7 real number fields, of which the first 2 are used. Format (10X,7F10.6).	Use the 2 numbers X and Y in one line of the answer to question 2(k), in the part titled "Sources", for each card.

6. Facility coordinate cards
(Leave out if ALPHA is blank or less than 0.0001)

Number of cards equal to NF, each card coded the same way as for source coordinate cards.	Use the part of question 2(k) titled "Facilities".

7. Solution storage criteria

One card containing 3 integer fields, of which the first 2 are used.
Format (2(5X,I10),10X,I5).

Use the answers to questions 2(l) and (m).

CASE START DECK

(see Figure 48 (b))

1. Title Card

One card containing 20 alphameric fields of 4 characters each.
Format (20A4).

Use the answer to question 3(a).

2. Source production cards

As many cards as required for NS entries with 5 integer fields per card.
Format (5(5X,I10)).

Use the answers to question 3(b).

3. Facility characteristics cards

Number of cards equal to NF, each containing 3 integer and 3 real number fields.
Format (5X,I10,2(5X,I10,E10.0), 5X,E10.0).

Obtain the six entries on each card by combining the corresponding lines in the answers to questions 3(c), (d) and (e), in this order with the exception that the second number in 3(c) should go in the 6th field rather than the 2nd field. Thus the order of the 6 numbers on a card, in terms of their labels in the questionnaire, should be "size limit", "fixed capital cost," "variable capital cost", "fixed O & M cost", "variable O & M cost" and "volume reduction ratio".

4. Indicator to permit all-year dead-end facilities to receive directly from sources; and the fraction WINTER

One card containing one integer and one real number field.
Format (5X,I1,14X,F10.9).

If the answer to question 3(f) is "yes" then the first number should be one, otherwise zero. For the number WINTER use 1.0 if the answer to either question 2(c) or (f) is zero; otherwise use the answer to question 3(g). Be sure WINTER is more than zero and not more than one.

5. Transport data mode I

One card containing 20 alphameric fields of 4 characters each, of which only the first field is used.
Format (20A4).

If the first box in question 3(h) is checked, enter the characters "ICST". If the second box is checked, enter the characters "IDST". If the third box is checked, enter any other characters or leave blank.

6. Haulage formula cards

(Leave out if I = "ICST")

One card plus as many cards as required to enter the numbers in the answer to question 3(i), the first card containing one integer field and the others containing 3 integer and 6 real number fields.
Format (I5/3(I5,2E10.0)).

On the first card enter the number of lines used in the answer to question 3(i). In each 3-field combination (I5,2E10.0) on the other cards enter the line number and the pair of numbers (a and b) in a line of the answer to question 3(i).

7. Transport data deck

(see Figure 49)

If I = "ICST":

Number of cards equal to NF times the number of cards required to enter a line of the table in question 3(j)
plus
the answer to 2(c) times the number of cards required to enter a line of the table in question 3(k)
plus
the answer to 2(e) times the number of cards required to enter a line of the table in question 3(1).
Each card contains 7 real number fields.
Format (10X,7F10.6).

Enter the numbers in each line labelled "c or d" as it occurs in the tables in question 3(j), (k), and (1). These numbers are called unit transport costs or values of C. Enter all of one line before starting the next line, and start a new card with each new line.
Be sure the number of lines used in question 3(j) is NF, the number used in 3(k) is the answer to 2(c) and the number used in 3(1) is the answer to 2(e). Be sure the number of columns used in 3(j) is NS, the number used in 3(k) is the answer to 2(f) and the number used in 3(1) is the answer to 2(d).

If I = "IDST":

Number of cards equal to twice what it would be if I were equal to "ICST". Proceeding from one line of the questionnaire answer tables to the next, you alternate between cards containing 7 integer fields each and cards containing 7 real number fields each.
Format (10X,7I10) alternating with Format (10X,7F10.6).

Enter the numbers in each line labelled "j or k" and "C or d" as it occurs in the tables in questions 3(j), (k) and (1). Use cards with the integer format for each line labelled "j or k"; these numbers are called haulage formula indicators or values of j. Use cards with the real number format for each line labelled "C or d"; these numbers are called trip lengths or values of d. Enter all of one line before starting the next line, and start a new card with each new line. The number of "j or k" lines used equals the number of "C or d" lines used. This and the number of columes used should be the same as if I were equal to "ICST",

I = neither "ICST" nor "IDST":

Number of cards is the same as if I were equal to "ICST". Each card contains 7 integer fields.
Format (10X,7I10).

Enter the numbers in each line labelled "j or k" as it occurs in the tables in question 3(j),(k), (1). These numbers are called haulage formula indicators or values of k. The remaining instructions are the same as if I were equal to "ICST", starting with "Enter all of one line before starting on the next line, etc."

8. Weight factor

One card containing 7 real number fields of which only the first one is used.
Format (10X,7F10.6)

Use the answer to question 3(m).
May be left blank if the answer to 2(c) or (f) is zero.

9. IDEFIN, ARBOUT, IDUMP, C*

One card containing 4 integer fields. Format (4(10X,I10)).	Use the answers to questions 3(n), (o), (p), and (q). Be sure ARBOUT and IDUMP are more than zero. C* may be left blank.

10. IDEF deck

(see Figure 50.)

(Leave out if IDEFIN is zero)

Number of cards as required to enter the lines of the answer to question 3(r), starting a new card with each new line, each card containing 25 integer fields. (Format (5X,25I3)	Enter all the numbers in each line of the answer to question 3(r). Be sure there are IDEFIN lines and in each line the number with the solid underscore equals the number of numbers on the dotted portion of the line. Be sure all numbers are more than zero and not more than NF, and those on the dotted portion of the line occur in increasing order.

11. COMBEX deck

(see Figure 51.)

(Leave out if IDEFIN is more than zero)

Inclusion cards and inclusion end card: Number of cards equal to one plus the number of numbers in the answer to question 3(s), each card containing 5 integer fields of which only the first one is used. Format (5(7X,I3)).	Enter one number in question 3(s) on each card. The last card, called the "inclusion end" card, must have a zero entered or be left blank. Be sure the other cards contain numbers that are more than zero and not more than NF.
Exclusion cards and exclusion end card: Number of cards equal to one plus the number of lines in answer to question 3(t), each card containing 5 integer fields of which the first 2 are used. Format (5(7X,I3)).	Enter two numbers in question 3(t) on each card, one line per card. The last card, called the "exclusion end" card, must have a zero entered or be left blank. Be sure the other cards contain numbers that are more than zero and not more than NF.
MAZSIZ card: One card containing 5 integer fields of which the first 4 are used. Format (5(7X,I3)).	Use the 4 answers to question 3(u).

CASE END CARD

One card containing 20 alphameric fields of 4 characters each, of which only the first field is used. Format (20A4).	Use the answer to question 3(v), entering data in all 20 fields as required. Except for the first field, this card may be considered a comment or marker for the Case Start deck. Be sure the first field does not contain the characters "====".

RUN END CARD

One card containing 20 alphameric fields of 4 characters each, of which only the first field is used. Format (20A4).	Use the answer to question 4(a), entering data in all 20 fields as required. Except for the first field, this card may be considered comment or marker for the end of the whole deck. Be sure the first field contains the characters "====".

end of Table

IV.2.2 Restart configuration

Refer to Figure 47(b). The title card in this configuration is different from that for the normal configuration: the first four characters must be "REST", as in "RESTART RUN B". The title is obtained from question 1(c) of the questionnaire. The Restart Deck is explained below; the next card, the first Case End card, may be obtained from either question 1(e) or 3(v). From there, proceed as for the normal configuration. Note that if the run is only to finish the terminated case and not do any new case of data then the Restart Deck is followed immediately by a Run End card obtained from question 4(a).

The last complete data dump must reside on input file unit IR2. If this unit is defined by the block data or by the system control cards to be the same as the input unit IR1 (usually the card reader), then the last complete data dump must be included in the Restart Deck as shown in Figure 52. Whether IR2 is the same as IR1 or not, the last complete data dump is obtained from the output file written on unit IW2 in the previous run which you are not restarting. Such a file is shown schematically in Figure 53. Each complete data dump is preceded by a card (or record) containing the word "RESTART" repeated several times, then followed by a card (or record) containing a statement giving the value of FACSET at which the data dump is completed. This same statement also appears in the IW1 dataset (i.e. the printout). The data dumps contain no other cards with similar characters, so these "leading" and "trailing" cards make it easy to locate each completed data dump. Of course, they should be removed from around the last complete data dump when it is used as the IR2 dataset.

If the answer to question 1(d) is more than zero, proceed with the IDEF Deck as for the normal configuration, using the answer to question 3(r) to obtain the remainder of the IDEF Deck for inclusion in the Restart Deck. In this case, the number of lines used in question 3(r) will likely be less than IDEFIN (= the answer to question 1(d)), since it is only the remainder of the IDEF Deck, i.e. that part not read by the previous terminated run, that the Restart Deck requires. Then continue with the first Case End card from question 3(v) or else the

Last Complete Data Dump — leave out if IR2 ≠ IR1

Remainder of IDEF Deck (if any) for terminated case to be continued

FIGURE 52. RESTART DECK

Notes: (1) "Last Complete Data Dump" must reside on input file unit IR2. It should be included here only if IR2 = IR1. The program knows whether IR1 = IR2 from their definition in the block data.

(2) If IDEFIN = 0 in a terminated case being continued, then there is no IDEF Deck, or remainder therof, to be included here.

Beginning of File

```
RESTART   RESTART   RESTART   RESTART   RESTART
          First Complete Data Dump
o* * * * * DATA DUMP COMPLETED AT FACSET = nnnnn ****

RESTART   RESTART   RESTART   RESTART   RESTART
          Second Complete Data Dump
o* * * * * DATA DUMP COMPLETED AT FACSET = nnnnn ****

                        .
                        .
                        .

RESTART   RESTART   RESTART   RESTART   RESTART
          Last Complete Data Dump
o* * * * * DATA DUMP COMPLETED AT FACSET = nnnnn****

RESTART   RESTART   RESTART   RESTART   RESTART
          Next Data Dump Incomplete
          (exists only if termination occurs during
           data dump)
```

End of File

FIGURE 53. OUTPUT FILE WRITTEN ON UNIT IW2

Run End card from question 4(a), as suitable, using formats as for the normal configuration.

If the answer to question 1(d) is zero, the Restart Deck will Contain no IDEF Deck. If, in addition, the last complete data dump is on an input unit different from IR1, the Restart Deck then does not really exist, i.e. no cards are put in for it. However, a Case End card is required, obtained from question 1(e) - Format (20A4); or, if there are no further cases in the run, a Run End card is used, as for the normal configuration.

IV.3 Data Deck Examples from the Niagara Study

In this section four data decks are shown. They are basically very similar, with the following differences: the first three contain one data case whereas the fourth contains three data cases; the facility and transport data are the same in the first three, but changed in the fourth; the first two specify a single facility combination for evaluation whereas the second two demand a complete survey of all possible combinations; and the second is the same as the first except that a different method is used for entering the transport data. The first, third and fourth decks were actually used in the Niagara study, for runs number 1, 4 and 16, respectively.

This section may be read in conjunction with the second section of Chapter 7, for a more thorough picture of the Niagara study.

IV.3.1 Run Number 1

The input data deck for run no. 1 is shown in Table 31.

The first card entitles the deck "Niagara Data Set Number Two - Using V. Red. Plants All Year". This was used on every data deck in these runs. It says that another set of data had been used before this one and that the present model contains volume reduction plants (drying lagoons, and vacuum filters) as all-year facilities.

The second card gives the size of the model: six sources, eight summer dead-end facilities (land spreading sites), zero all-year intermediate facilities, 11 all-year dead-end facilities (the drying lagoons and vacuum filters with ultimate disposal assumed in their cost functions), and eight winter intermediate facilities (holding tanks).

TABLE 31. INPUT DATA FOR RUN NUMBER 1

```
             NIAGARA DATA SET NUMBER TWO   -  USING VRED PLANTS ALL YEAR
         6         8         0        11         8
 1  GMLN  GRIMSBY-LINCOLN
 2  PWDH  PORT WELLER AND PORT DALHOUSIE, COMBINED
 3  NFLS  NIAGARA FALLS
 4  FERI  FORT ERIE
 5  PCBN  PORT COLBORNE
 6  WLND  WELLAND
 1  FELS  LANDSPREAD AT FORT ERIE
 2  NELS  LANDSPREAD AT NETHERBY
 3  PCLS  LANDSPREAD AT PORT COLBORNE
 4  PALS  LANDSPREAD AT POINT ALBINO
 5  CYLS  LANDSPREAD AT CYANAMID
 6  RSLS  LANDSPREAD AT ROSEDENE
 7  WFLS  LANDSPREAD AT WAINFLEET
 8  CSLS  LANDSPREAD AT CAISTORVILLE
 9  FEDL  DRYING LAGOON AT FORT ERIE              (OUTPUT TO FELS)
10  NEDL  DRYING LAGOON AT NETHERBY               (OUTPUT TO NELS)
11  PCDL  DRYING LAGOON AT PORT COLBORNE          (OUTPUT TO PCLS)
12  PADL  DRYING LAGOON AT POINT ALBINO           (OUTPUT TO PALS)
13  CYDL  DRYING LAGOON AT CYANAMID               (OUTPUT TO CYLS)
14  RSDL  DRYING LAGOON AT ROSEDENE               (OUTPUT TO RSLS)
15  WFDL  DRYING LAGOON AT WAINFLEET              (OUTPUT TO WFLS)
16  CSDL  DRYING LAGOON AT CAISTORVILLE           (OUTPUT TO CSLS)
17  PDVF  VACUUM FILTER AT PORT DALHOUSIE         (OUTPUT TO FELS)
18  NFVF  VACUUM FILTER AT NIAGARA FALLS          (OUTPUT TO CYLS)
19  WDVF  VACUUM FILTER AT WELLAND                (OUTPUT TO PCLS)
20  FEHT  HOLDING TANK AT FORT ERIE
21  NEHT  HOLDING TANK AT NETHERBY
22  PCHT  HOLDING TANK AT PORT COLBORNE
23  PAHT  HOLDING TANK AT POINT ALBINO
24  CYHT  HOLDING TANK AT CYANAMID
25  RSHT  HOLDING TANK AT ROSEDENE
26  WFHT  HOLDING TANK AT WAINFLEET
27  CSHT  HOLDING TANK AT CAISTORVILLE
ALPHA                 0
         100000             20
                   DATA CASE FOR 1974
SOUR10000352000SOUR20008414000SOUR30002448000SOUR40000184000SOUR50000894000
SOUR60000800000
01LIM0001550000.CAPC         0       0+0.OAMC         0       0+0.VRED
02             .CAPC         0      35-4.OAMC         0      15-4.VRED
03   0002150000.CAPC         0       0+0.OAMC         0       0+0.VRED
04             .CAPC         0      35-4.OAMC         0      15-4.VRED
05             .CAPC         0      35-4.OAMC         0      15-4.VRED
06LIM          .CAPC         0      35-4.OAMC         0      15-4.VRED
07LIM          .CAPC         0      35-4.OAMC         0      15-4.VRED
08LIM          .CAPC         0      35-4.OAMC         0      15-4.VRED
09LIM0002580000.CAPC         000052222-7.OAMC         0     468-8.VRED      26-2
10LIM0009000000.CAPC         0      13-3.OAMC         0  280468-8.VRED      26-2
11LIM0003580000.CAPC         0   52222-7.OAMC         0     468-8.VRED      26-2
12LIM   9000000.CAPC         0      13-3.OAMC         0  280468-8.VRED      26-2
13LIM   9000000.CAPC         0      13-3.OAMC         0  280468-8.VRED      26-2
14LIM   9000000.CAPC         0      13-3.OAMC         0  280468-8.VRED      26-2
15LIM   9000000.CAPC         0      13-3.OAMC         0  280468-8.VRED      26-2
16LIM   9000000.CAPC         0      13-3.OAMC         0  280468-8.VRED      26-2
17LIM   5900000.CAPC      3000       0+0.OAMC     35000   10322-6.VRED
18LIM   2450000.CAPC      3000       0+0.OAMC     35000  177288-7.VRED
19LIM   1800000.CAPC      3000       0+0.OAMC     35000  261448-7.VRED
20LIM          .CAPC      3000   13991-7.OAMC       200      74-7.VRED       1+0
```

TABLE 31. (CONT'D)

21LIM	.CAPC	3000	23045-7	.0AMC	200	74-7.VREF0	1+0
22LIM	.CAPC	3000	13991-7	.0AMC	200	74-7.VREF0	1+0
23LIM	.CAPC	3000	23045-7	.0AMC	200	74-7.VREF0	1+0
24LIM	.CAPC	3000	23045-7	.0AMC	200	74-7.VREF0	1+0
25LIM	.CAPC	3000	23045-7	.0AMC	200	74-7.VREF0	1+0
26LIM	.CAPC	3000	23045-7	.0AMC	200	74-7.VREF0	1+0
27LIM	.CAPC	3000	23045-7	.0AMC	200	74-7.VREF0	1+0
LIQLF1	WINTER	0.5					
IDST							
3							
1	4-3	6-3 2	0+0	72-6	3	0+0	1+0
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.01	2100000	1400000	900000	266667	1333333	1333333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.02	1750000	1500000	1200000	866667	933333	666667	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.03	1950000	1766667	1666667	1733333	400200	500000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.04	2100000	1966667	2000000	1400000	666667	1200000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.05	1700000	1433333	800000	1466667	1200000	533333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.06	800000	1500000	1466667	1950000	1533333	1133333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.07	2000000	1800000	1733333	1933333	533333	933333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.08	1466667	2633333	2600000	2800000	2666667	2266667	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.09	2100000	1400000	900000	266667	1333333	1333333	
HAUL.FORM.	1	1	1	1	1	3	0
DIST.TO.10	1750000	1500000	1200000	866667	933333	0000800	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.11	1950000	1766667	1666667	1733333	400000	500000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.12	2100000	1966667	2000000	1400000	666667	1200000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.13	1700000	1433333	800000	1466667	1200000	533333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.14	800000	1500000	1466667	1950000	1533333	1133333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.15	2000000	1800000	1733333	1933333	533333	933333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.16	1466667	2633333	2600000	2800600	2666667	2266667	
HAUL.FORM.	1	3	1	1	1	1	0
DIST.TO.17	1133333	0003000	1000000	1700000	1600000	1266667	
HAUL.FORM.	1	1	3	1	1	1	0
DIST.TO.18	1866667	1066667	0000000	1250000	1600000	1066667	
HAUL.FORM.	1	1	1	1	1	3	0
DIST.TO.19	1650000	1333333	1066667	1466667	600000	0000000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.20	2100000	1400000	900000	266667	1333333	1333333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.21	1750000	1500000	1200000	866667	933333	666667	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.22	1950000	1766667	1666667	1733333	400000	500000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.23	2100000	1966667	2000000	1400000	666667	1200000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.24	1700000	1433333	800000	1466667	1200000	533333	
HAUL.FORM.	1	1	1	1	1	1	

TABLE 31. (CONT'D)

```
DIST.TO.25     800000   1500000   1466667   1950000   1533333   1133333
HAUL.FORM.          1         1         1         1         1         1         0
DIST.TO.26    2000000   1800000   1733333   1933333    533333    933333
HAUL.FORM.          1         1         1         1         1         1         0
DIST.TO.27    1466667   2633333   2600000   2600000   2666667   2266667
HAUL.FORM.          2         1         1         1         1         1         1
HAUL.FORM.          1         0         0         0         0         0         0
DIST.TO.01     250000    733333   1333333    800000   1200000   1750000   1533333
              2450000
HAUL.FORM.          1         2         1         1         1         1         1
HAUL.FORM.          1         0         0         0         0         0         0
DIST.TO.02     733333    250000   1200000    700000    800000   1666667   1533333
              2733333
HAUL.FORM.          1         1         2         1         1         1         1
HAUL.FORM.          1         0         0         0         0         0         0
DIST.TO.03    1333333   1200000    250000    933333   1100000   1266667    533333
              2066667
HAUL.FORM.          1         1         1         2         1         1         1
HAUL.FORM.          1         0         0         0         0         0         0
DIST.TO.04     800000    700000    933333    250000   1000000   1933333   1800000
              2566667
HAUL.FORM.          1         1         1         1         2         1         1
HAUL.FORM.          1         0         0         0         0         0         0
DIST.TO.05    1200000    800000   1100000   1000000    250000   1400000   1466667
              2000000
.AUL.FORM.          1         1         1         1         1         2         1
.AUL.FORM.          1         0         0         0         0         0         0
DIST.TO.06    1750000   1666667   1266667   1933333   1400000    250000    933333
              1266667
.AUL.FORM.          1         1         1         1         1         1         2
.AUL.FORM.          1         0         0         0         0         0         0
DIST.TO.07    1533333   1533333    533333   1800000   1466667    933333    250000
              1600000
.AUL.FORM.          1         1         1         1         1         1         1
.AUL.FORM.          2         0         0         0         0         0         0
DIST.TO.08    2450000   2733333   2066667   2566667   2000000   1266667   1600000
               250000
WEIGHTFAC.   -2
    IDEFIN          1    ARROUT         1
      27  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
      25 26 27
====    END OF LAST CASE
```

Then there are 33 cards giving abbreviated names for the sources and facilities along with explanatory comments. Then a card giving ALPHA the value zero, which tells the program there are no coordinates in the data and no case in the run requires trip lengths that it must calculate from coordinates. Then a card giving EPS the value 100000 and MAXSOL the value 20. This is a relatively large value for EPS: the intention was to obtain 20 solutions no matter how wide a range in cost they were. As it turned out, it could have been reduced by a factor of about ten without changing the results, and this would have speeded up the program's solution screening process.

These 37 cards discussed so far were the same in every run in this study.

Then the data case used in run no. 1 appears, beginning with a title card stating the year, since in every run with more than one case the year was sufficient to distinguish between different data cases. The cards giving the source outputs contain labels "sour1", "sour2", etc., standing for source no. 1, source no. 2, etc. Any other labels could also have been used, or they could have been left blank. The cards continuing the facility information also have labels: first the facility number, then "lim" for facility size limit then "capc" for capital cost coefficients, then "oamc" for operating and maintenance cost coefficients, and finally "vred" for volume reduction ratio. Such labels make the data deck quite meaningful for the user to read.

Note that, although volume reduction ratios are entered for the drying lagoons, they are not used by the program since these facilities are being modelled as dead-end facilities.

Next is a card giving LIQLF the value of 1, telling the program that the model includes transport links from sources directly to all-year dead-end facilities, and WINTER the value 0.5, telling the program that the summer dead-end facilities cannot be used during one-half of the year.

The transport cost information follows, beginning with a card giving the method by which the data are entered. The letters "IDST" tell the program that Method 2 is being used. This method was used in all these runs. Then there is a card giving the number of haulage formulas as three, followed by a card giving the values of a and b for these haulage formulas. The transport cost information is completed with 86 cards giving haulage formula indicators and trip lengths for each transport link as required by Method 2. The decimal point in the trip lengths appears six places from the end. These data entries are all in the same arrangement as in Table 13 and Table 14. These 86 cards were the same in each of these runs and in every case in a run; for data modifications, only the card containing the haulage formulas was changed. The first 10 characters on each card are labels, not read by the program: "haul.form." for haulage formula indicator, and "dist.to.nn" for trip length to the facility to the given number nn.

After the transport cost information, there is a card giving the weight factor the value -2 and a card saying that specific combinations of facilities to be given in the data should be evaluated (just one) and that the optimized distribution should be printed out, before screening, for every one of them. This card also indicates, by leaving off a third number, that no data dump for restarting the run is to be made.

Finally, the facility combination to be evaluated is given, starting with the total number of facilities in the combination (all 27). If more combinations were to be evaluated, they would also be specified here. A card beginning with the characters "====" then indicates that there are no other data cases in this run and the program should stop.

IV.3.2 Run Number 1, illustrating alternate method

For the sake of illustrating the difference, Table 32 shows the input data deck that would be required for run no. 1 if Method 1 was used to enter the transport cost information rather than Method 2. The method is indicated by a card with the letters "ICST" rather than "IDST". There are no haulage formulas, and each haulage formula indicator and trip length is replaced by a single number giving the actual cost per gallon for the transport link. The decimal point in these numbers comes one place before the first digit shown.

Thus, the transport information cards are cut by 50% in volume, but these 226 coefficients had to be calculated and with each data modification, they would have to be recalculated. It is much easier to use

TABLE 32. RUN NUMBER 1 - ALTERNATE METHOD

```
                 NIAGARA DATA SET NUMBER TWO  -  USING VRED PLANTS ALL YEAR
            6         8         0         11         8
1   GMLN    GRIMSBY-LINCOLN
2   PWDH    PORT WELLER AND PORT DALHOUSIE, COMBINED
3   NFLS    NIAGARA FALLS
4   FERI    FORT ERIE
5   PCBN    PORT COLBORNE
6   WLND    WELLAND
1   FELS    LANDSPREAD AT FORT ERIE
2   NELS    LANDSPREAD AT NETHERBY
3   PCLS    LANDSPREAD AT PORT COLBORNE
4   PALS    LANDSPREAD AT POINT ALBINO
5   CYLS    LANDSPREAD AT CYANAMID
6   RSLS    LANDSPREAD AT ROSEDENE
7   WFLS    LANDSPREAD AT WAINFLEET
8   CSLS    LANDSPREAD AT CAISTORVILLE
9   FEDL    DRYING LAGOON AT FORT ERIE                   (OUTPUT TO FELS)
10  NEDL    DRYING LAGOON AT NETHERBY                    (OUTPUT TO NELS)
11  PCDL    DRYING LAGOON AT PORT COLBORNE               (OUTPUT TO PCLS)
12  PADL    DRYING LAGOON AT POINT ALBINO                (OUTPUT TO PALS)
13  CYDL    DRYING LAGOON AT CYANAMID                    (OUTPUT TO CYLS)
14  RSDL    DRYING LAGOON AT ROSEDENE                    (OUTPUT TO RSLS)
15  WFDL    DRYING LAGOON AT WAINFLEET                   (OUTPUT TO WFLS)
16  CSDL    DRYING LAGOON AT CAISTORVILLE                (OUTPUT TO CSLS)
17  PDVF    VACUUM FILTER AT PORT DALHOUSIE              (OUTPUT TO FELS)
18  NFVF    VACUUM FILTER AT NIAGARA FALLS               (OUTPUT TO CYLS)
19  WDVF    VACUUM FILTER AT WELLAND                     (OUTPUT TO PCLS)
20  FEHT    HOLDING TANK AT FORT ERIE
21  NEHT    HOLDING TANK AT NETHERBY
22  PCHT    HOLDING TANK AT PORT COLBORNE
23  PAHT    HOLDING TANK AT POINT ALBINO
24  CYHT    HOLDING TANK AT CYANAMID
25  RSHT    HOLDING TANK AT ROSEDENE
26  WFHT    HOLDING TANK AT WAINFLEET
27  CSHT    HOLDING TANK AT CAISTORVILLE
ALPHA             0
           100000                  20
                    DATA CASE FOR 1974
SOUR10000332000SOUR20008414000SOUR30002448000SOUR40000184000SOUR50000894000
SOUR60000600000
01LIM00015500000.CAPC          0        0+0.0AMC          0         0+0.VRED
02               .CAPC          0       35-4.0AMC          0        15-4.VRED
03    00021500000.CAPC          0        0+0.0AMC          0         0+0.VRED
04               .CAPC          0       35-4.0AMC          0        15-0.VRED
05               .CAPC          0       35-4.0AMC          0        15-4.VRED
06LIM            .CAPC          0       35-4.0AMC          0        15-4.VRED
07LIM            .CAPC          0       35-4.0AMC          0        15-4.VRED
08LIM            .CAPC          0       35-4.0AMC          0        15-4.VRED
09LIM00025800000.CAPC          000052222-7.0AMC          0       168-8.VRED          26-2
10LIM00090000000.CAPC          0       13-3.0AMC          0    280168-8.VRED          26-2
11LIM00035800000.CAPC          0    52222-7.0AMC          0       168-8.VRED          26-2
12LIM    9000000.CAPC          0       13-3.0AMC          0    280168-8.VRED          26-2
13LIM    9000000.CAPC          0       13-3.0AMC          0    280168-8.VRED          26-2
14LIM    9000000.CAPC          0       13-3.0AMC          0    280168-8.VRED          26-2
15LIM    9000000.CAPC          0       13-3.0AMC          0    280163-8.VRED          26-2
16LIM    9000000.CAPC          0       13-3.0AMC          0    280168-8.VRED          26-2
17LIM    5900000.CAPC       3000        0+0.0AMC      35000      10322-6.VRED
18LIM    2450000.CAPC       3000        0+0.0AMC      35000     177288-7.VRED
19LIM    1600000.CAPC       3000        0+0.0AMC      35000     261168-7.VRED
20LIM            .CAPC       3000    13991-7.0AMC        206        74-7.VRED          1+0
```

TABLE 32. (CONT'D)

```
21LIM            .CAPC        3000   23045-7.0AMC        200     74-7.VRED        1+0
22LIM            .CAPC        3000   13991-7.0AMC        200     74-7.VRED        1+0
23LIM            .CAPC        3000   23045-7.0AMC        200     74-7.VRED        1+0
24LIM            .CAPC        3000   23045-7.0AMC        200     74-7.VRED        1+0
25LIM            .CAPC        3000   23045-7.0AMC        200     74-7.VRED        1+0
26LIM            .CAPC        3000   23045-7.0AMC        200     74-7.VRED        1+0
27LIM            .CAPC        3000   23045-7.0AMC        200     74-7.VRED        1+0
LIQLF1          WINTER  0.5
ICST
COST.TO.01       16600       12400       09400       05600       12000       12000
COST.TO.02       14500       13000       11200       09200       09600       08000
COST.TO.03       15700       14600       14000       14400       06400       07000
COST.TO.04       16600       15800       16000       12400       08000       11200
COST.TO.05       14200       12600       08800       12800       11200       07200
COST.TO.06       08800       13000       12800       15700       13200       10800
COST.TO.07       16000       14800       14400       15600       07200       09600
COST.TO.08       12800       19800       19600       20800       20000       17600
COST.TO.09       16600       12400       09400       05600       12000       12000
COST.TO.10       14500       13000       11200       09200       09600       00800
COST.TO.11       15700       14600       14000       14400       06400       07000
COST.TO.12       16600       15800       16000       12400       08000       11200
COST.TO.13       14200       12600       08800       12800       11200       07200
COST.TO.14       08800       13000       12800       15700       13200       10800
COST.TO.15       16000       14800       14400       15600       07200       09600
COST.TO.16       12800       19800       19600       20800       20000       17600
COST.TO.17       10800       03000       10000       14200       13600       11600
COST.TO.18       15200       10400       00000       11500       13600       10400
COST.TO.19       13900       12000       10400       12800       07600       00000
COST.TO.20       16600       12400       09400       05600       12000       12000
COST.TO.21       14500       13000       11200       09200       09600       08000
COST.TO.22       15700       14600       14000       14400       06400       07000
COST.TO.23       16600       15800       16000       12400       08000       11200
COST.TO.24       14200       12600       08800       12800       11200       07200
COST.TO.25       08800       13000       12800       15700       13200       10800
COST.TO.26       16000       14800       14400       15600       07200       09600
COST.TO.27       12800       19800       19600       20800       20000       17600
COST.TO.01       00018       08400       12000       06800       11200       14500       13200
COST.TO.01       18700
COST.TO.02       08400       00018       11200       08200       08800       14000       13200
COST.TO.02       20400
COST.TO.03       12000       11200       00018       09600       10600       11600       07200
COST.TO.03       16400
COST.TO.04       08800       08200       09600       00018       10000       15600       14800
COST.TO.04       19400
COST.TO.05       11200       08800       10600       10000       00018       12400       12800
COST.TO.05       16000
COST.TO.06       14500       14000       11600       15600       12400       00018       09600
COST.TO.06       11600
COST.TO.07       13200       13200       07200       14800       12800       09600       00018
COST.TO.07       13600
COST.TO.08       18700       20400       16400       19400       16000       11600       13600
COST.TO.08       00018
WEIGHTFAC.   -2
    IDEFIN               1     AGGOUT        1
      27  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
      25 26 27
====    END OF LAST CASE
```

haulage formulas and have the computer perform the calculations for each data case as required.

IV.3.3 Run Number 4

The input data deck for run no. 4 is shown in Table 33. It is the same as Table 31 (run no. 1) up until the card that gives the value of the weight factor. This value is now zero, as this was the best value found in runs 1, 2, and 3. The next card says that there are no facility combinations specified in the data; that every 300th facility combination generated by the program should have its optimized distribution printed out before it is screened; and after evaluation of every 1000th facility combination, a data dump should be made for possible restarting of the run.

These last two numbers, ARBOUT and IDUMP, respectively, were chosen with the knowledge that there would be about 2000 facility combinations generated by the program. This estimate was obtained by calculating 2^{27-16}, where 27 is the total number of potential facilities and 16 is the number of them that, as they have zero fixed charge, are entered in the following cards so that they will be included in every combination. These cards are labelled "inc" and each one contains one facility number. The last of these "inc" cards contains the number zero to tell the program that this type of information has ended. Next, if it were applicable, would be information giving the facility pairs that should not exist in any combination. We like to label these cards "nobloc". A card with zeros in place of facility numbers tells the program to go on to the last data card. This last card contains the maximum values for the number of facilities of each kind that may exist in a combination of facilities. We use the value six for each of these, except when there are no facilities of the given type, since there are six sources. However, the "inc" cards here override these maximum values, except for the fourth type of facility (facilities 20 to 27, the holding tanks).

Finally, a card beginning with "====" tells the program there are no more data cases in the run and it must stop.

TABLE 33. INPUT DATA FOR RUN NUMBER 4

```
          NIAGARA DATA SET NUMBER TWO  -  USING VRED PLANTS ALL YEAR
         6         8         0        11         8
 1  GMLN  GRIMSBY-LINCOLN
 2  PWDH  PORT WELLER AND PORT DALHOUSIE, COMBINED
 3  NFLS  NIAGARA FALLS
 4  FERT  FORT ERIE
 5  PCBN  PORT COLBORNE
 6  WLND  WELLAND
 1  FELS  LANDSPREAD AT FORT ERIE
 2  NELS  LANDSPREAD AT NETHERBY
 3  PCLS  LANDSPREAD AT PORT COLBORNE
 4  PALS  LANDSPREAD AT POINT ALBINO
 5  CYLS  LANDSPREAD AT CYANAMID
 6  RSLS  LANDSPREAD AT ROSEDENE
 7  WFLS  LANDSPREAD AT WAINFLEET
 8  CSLS  LANDSPREAD AT CAISTORVILLE
 9  FEDL  DRYING LAGOON AT FORT ERIE                (OUTPUT TO FELS)
10  NEDL  DRYING LAGOON AT NETHERBY                 (OUTPUT TO NELS)
11  PCDL  DRYING LAGOON AT PORT COLBORNE            (OUTPUT TO PCLS)
12  PADL  DRYING LAGOON AT POINT ALBINO             (OUTPUT TO PALS)
13  CYDL  DRYING LAGOON AT CYANAMID                 (OUTPUT TO CYLS)
14  RSDL  DRYING LAGOON AT ROSEDENE                 (OUTPUT TO RSLS)
15  WFDL  DRYING LAGOON AT WAINFLEET                (OUTPUT TO WFLS)
16  CSDL  DRYING LAGOON AT CAISTORVILLE             (OUTPUT TO CSLS)
17  PDVF  VACUUM FILTER AT PORT DALHOUSIE           (OUTPUT TO FELS)
18  NFVF  VACUUM FILTER AT NIAGARA FALLS            (OUTPUT TO CYLS)
19  WDVF  VACUUM FILTER AT WELLAND                  (OUTPUT TO PCLS)
20  FEHT  HOLDING TANK AT FORT ERIE
21  NEHT  HOLDING TANK AT NETHERRBY
22  PCHT  HOLDING TANK AT PORT COLBORNE
23  PAHT  HOLDING TANK AT POINT ALBINO
24  CYHT  HOLDING TANK AT CYANAMID
25  RSHT  HOLDING TANK AT ROSEDENE
26  WFHT  HOLDING TANK AT WAINFLEET
27  CSHT  HOLDING TANK AT CAISTORVILLE
ALPHA         0
        100000            20
                DATA CASE FOR 1974
SOUR100003320000SOUR200084140000SOUR300024880000SOUR400001840000SOUR500008940000
SOUR60000800000
01LIM0001550000.CAPC         0       0+0.OAMC        0       0+0.VRED
02                  .CAPC         0      35-4.OAMC        0      15-4.VRED
03    000215000O.CAPC         0       0+0.OAMC        0       0+0.VRED
04             .CAPC         0      35-4.OAMC        0      15-4.VRED
05             .CAPC         0      35-4.OAMC        0      15-4.VRED
06LIM          .CAPC         0      35-4.OAMC        0      15-4.VRED
07LIM          .CAPC         0      35-4.OAMC        0      15-4.VRED
08LIM          .CAPC         0      35-4.OAMC        0      15-4.VRED
09LIM0002580000.CAPC         000052222-7.OAMC        0     468-6.VRED       26-2
10LIM0009000000.CAPC         0      13-3.OAMC        0  280468-8.VRED       26-2
11LIM0003580000.CAPC         0   52222-7.OAMC        0     468-6.VRED       26-2
12LIM    9000000.CAPC         0      13-3.OAMC        0  280468-8.VRED       26-2
13LIM    9000000.CAPC         0      13-3.OAMC        0  280468-8.VRED       26-2
14LIM    9000000.CAPC         0      13-3.OAMC        0  280468-8.VRED       26-2
15LIM    9000000.CAPC         0      13-3.OAMC        0  280468-8.VRED       26-2
16LIM    9000000.CAPC         0      13-3.OAMC        0  280468-8.VRED       26-2
17LIM    5900000.CAPC      3000       0+0.OAMC    35000    10322-6.VRED
18LIM    2450000.CAPC      3000       0+0.OAMC    35000  177252-7.VRED
19LIM    1800000.CAPC      3000       0+0.OAMC    35000  261468-7.VRED
20LIM          .CAPC      3000   13991-7.OAMC      200      74-7.VRED        1+0
```

TABLE 33. (CONT'D)

```
21LIM           .CAPC       3000   23045-7.0AMC       200       74-7.VRF0          1+0
22LIM           .CAPC       3000   13991-7.0AMC       200       74-7.VRF0          1+0
23LIM           .CAPC       3000   23045-7.0AMC       200       74-7.VRF0          1+0
24LIM           .CAPC       3000   23045-7.0AMC       200       74-7.VRF0          1+0
25LIM           .CAPC       3000   23045-7.0AMC       200       74-7.VRF0          1+0
26LIM           .CAPC       3000   23045-7.0AMC       200       74-7.VRF0          1+0
27LIM           .CAPC       3000   23045-7.0AMC       200       74-7.VRF0          1+0
LIQLF1        WINTER     0.5
IDST
    3
    1         4-3        6-3        2       0+0       72-6     3        0+0       1+0
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.01    2100000    1400000     900000     266667    1333333    1333333
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.02    1750000    1500000    1200000     866667     933333     666667
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.03    1950000    1766667    1666667    1733333     400000     500000
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.04    2100000    1966667    2000000    1400000     666667    1200000
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.05    1700000    1433333     800000    1466667    1200000     533333
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.06     800000    1500000    1466667    1950000    1533333    1133333
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.07    2000000    1800000    1733333    1933333     533333     933333
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.08    1466667    2633333    2600000    2800000    2666667    2266667
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.09    2100000    1400000     900000     266667    1333333    1333333
HAUL.FORM.          1          1          1          1          1          3          0
DIST.TO.10    1750000    1500000    1200000     866667     933333    0000800
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.11    1950000    1766667    1666667    1733333     400000     500000
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.12    2100000    1966667    2000000    1400000     666667    1200000
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.13    1700000    1433333     800000    1466667    1200000     533333
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.14     800000    1500000    1466667    1950000    1533333    1133333
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.15    2000000    1800000    1733333    1933333     533333     933333
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.16    1466667    2633333    2600000    2800000    2666667    2266667
HAUL.FORM.          1          3          1          1          1          1          0
DIST.TO.17    1133333    0003000    1000000    1700000    1600000    1266667
HAUL.FORM.          1          1          3          1          1          1          0
DIST.TO.18    1866667    1066667    0000000    1250000    1600000    1066667
HAUL.FORM.          1          1          1          1          1          3          0
DIST.TO.19    1650000    1333333    1066667    1466667     600000    0000000
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.20    2100000    1400000     900000     266667    1333333    1333333
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.21    1750000    1500000    1200000     866667     933333     666667
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.22    1950000    1766667    1666667    1733333     400000     500000
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.23    2100000    1966667    2000000    1400000     666667    1200000
HAUL.FORM.          1          1          1          1          1          1          0
DIST.TO.24    1700000    1433333     800000    1466667    1200000     533333
HAUL.FORM.          1          1          1          1          1          1          0
```

TABLE 33. (CONT'D)

```
DIST.TO.25      800000   1500000   1466667   1950000   1533333   1133333
HAUL.FORM.           1         1         1         1         1         1         0
DIST.TO.26     2000000   1800000   1733333   1933333    533333    933333
HAUL.FORM.           1         1         1         1         1         1         0
DIST.TO.27     1466667   2633333   2600000   2800000   2666667   2266667
HAUL.FORM.           2         1         1         1         1         1         1
HAUL.FORM.           1         0         0         0         0         0         0
DIST.TO.01      250000    733333   1333333    800000   1200000   1750000   1533333
               2450000
HAUL.FORM.           1         2         1         1         1         1         1
HAUL.FORM.           1         0         0         0         0         0         0
DIST.TO.02      733333    250000   1200000    700000    800000   1666667   1533333
               2733333
HAUL.FORM.           1         1         2         1         1         1         1
HAUL.FORM.           1         0         0         0         0         0         0
DIST.TO.03     1333333   1200000    250000    933333   1100000   1266667    533333
               2066667
HAUL.FORM.           1         1         1         2         1         1         1
HAUL.FORM.           1         0         0         0         0         0         0
DIST.TO.04      800000    700000    933333    250000   1000000   1933333   1800000
               2566667
HAUL.FORM.           1         1         1         1         2         1         1
HAUL.FORM.           1         0         0         0         0         0         0
DIST.TO.05     1200000    800000   1100000   1000000    250000   1400000   1466667
               2000000
.AUL.FORM.           1         1         1         1         1         2         1
.AUL.FORM.           1         0         0         0         0         0         0
DIST.TO.06     1750000   1666667   1266667   1933333   1400000    250000    933333
               1266667
.AUL.FORM.           1         1         1         1         1         1         2
.AUL.FORM.           1         0         0         0         0         0         0
DIST.TO.07     1533333   1533333    533333   1800000   1466667    933333    250000
               1600000
.AUL.FORM.           1         1         1         1         1         1         1
.AUL.FORM.           2         0         0         0         0         0         0
DIST.TO.08     2450000   2733333   2066667   2566667   2000000   1266667   1600000
                250000
WEIGHTFAC.    0
                     0                 300                1000
INC        1
INC        2
INC        3
INC        4
INC        5
INC        6
INC        7
INC        8
INC        9
INC       10
INC       11
INC       12
INC       13
INC       14
INC       15
INC       16
INC       00
NOBLOC     0         0
MAXSIZ     6         0         6         6
====      END OF LAST CASE
```

IV.3.4 Run Number 16

To show the difference in an input data deck for a run with more than one case, Table 34 shows the deck for run no. 16. The 1974 data case in this deck may also be compared to that in Table 33 to see the difference made by data modification 1.

It can be seen that, at the end of a data case, if another data case is to be used in the run, there is a card containing a comment indicating the end of the case without beginning with the characters "====". Then the next data case begins.

The third to the sixth cards in the deck contain a comment regarding the data modification. Any such comments may be made on the right side of the "name abbreviation" cards and they will appear in the printout.

The only difference between the 1974 data case here and that in Table 33 is the haulage formula card. The 1980 and 1990 data cases also have this different haulage formula card, and in each case the size limits on facilities 17 to 19 (the vacuum filters) are raised.

TABLE 34. INPUT DATA FOR RUN NUMBER 16

```
          NIAGARA DATA SET NUMBER TWO  -  USING [illegible] PLANTS ALL YEAR
         6        8        0        11        8
 1  GMLN  GRIMSBY-LINCOLN                          ////IN THIS RUN THE LOADING
 2  PWDH  PORT WELLER AND PORT DALHOUSIE, COMBINED     COSTS ARE HIGHER...
 3  NFLS  NIAGARA FALLS                                 ALSO THE VF SIZE LIMITS
 4  FERI  FORT ERIE                                     ARE RAISED WITH TIME////
 5  PCBO  PORT COLBORNE
 6  WLND  WELLAND
 1  FELS  LANDSPREAD AT FORT ERIE
 2  NELS  LANDSPREAD AT NETHERBY
 3  PCLS  LANDSPREAD AT PORT COLBORNE
 4  PALS  LANDSPREAD AT POINT ALBINO
 5  CYLS  LANDSPREAD AT CYANAMID
 6  RSLS  LANDSPREAD AT ROSEDENE
 7  WFLS  LANDSPREAD AT WAINFLEET
 8  CSLS  LANDSPREAD AT CAISTORVILLE
 9  FEDL  DRYING LAGOON AT FORT ERIE             (OUTPUT TO FELS)
10  NEDL  DRYING LAGOON AT NETHERBY              (OUTPUT TO NELS)
11  PCDL  DRYING LAGOON AT PORT COLBORNE         (OUTPUT TO PCLS)
12  PADL  DRYING LAGOON AT POINT ALBINO          (OUTPUT TO PALS)
13  CYDL  DRYING LAGOON AT CYANAMID              (OUTPUT TO CYLS)
14  RSDL  DRYING LAGOON AT ROSEDENE              (OUTPUT TO RSLS)
15  WFDL  DRYING LAGOON AT WAINFLEET             (OUTPUT TO WFLS)
16  CSDL  DRYING LAGOON AT CAISTORVILLE          (OUTPUT TO CSLS)
17  PDVF  VACUUM FILTER AT PORT DALHOUSIE        (OUTPUT TO FELS)
18  NFVF  VACUUM FILTER AT NIAGARA FALLS         (OUTPUT TO CYLS)
19  WDVF  VACUUM FILTER AT WELLAND               (OUTPUT TO PCLS)
20  FEHT  HOLDING TANK AT FORT ERIE
21  NEHT  HOLDING TANK AT NETHERBY
22  PCHT  HOLDING TANK AT PORT COLBORNE
23  PAHT  HOLDING TANK AT POINT ALBINO
24  CYHT  HOLDING TANK AT CYANAMID
25  RSHT  HOLDING TANK AT ROSEDENE
26  WFHT  HOLDING TANK AT WAINFLEET
27  CSHT  HOLDING TANK AT CAISTORVILLE
ALPHA            0
          100000             20
                   DATA CASE FOR 1974
SOUR10000352050SOUR20008414000SOUR30002448000SOUR40000124000SOUR50000828000
SOUR60000000000
01LIM00015500000.CAPC        0        0+0.0AMC       0        0+0.VRED
02              .CAPC        0       35-4.0AMC       0       15-4.VRED
03     00021500000.CAPC      0        0+0.0AMC       0        0+0.VRED
04              .CAPC        0       35-4.0AMC       0       15-4.VRED
05              .CAPC        0       35-4.0AMC       0       15-4.VRED
06LIM           .CAPC        0       35-4.0AMC       0       15-4.VRED
07LIM           .CAPC        0       35-4.0AMC       0       15-4.VRED
08LIM           .CAPC        0       35-4.0AMC       0       15-4.VRED
09LIM00025300000.CAPC        000052222-7.0AMC    0         168-8.VRED       26-2
10LIM00020900000.CAPC        0       13-3.0AMC       0    280168-8.VRED       26-2
11LIM00025900000.CAPC        0     .52222-7.0AMC     0         168-8.VRED       26-2
12LIM     9000000.CAPC       0       13-3.0AMC       0    280168-8.VRED       26-2
13LIM     9000000.CAPC       0       13-3.0AMC       0    280168-8.VRED       26-2
14LIM     9000000.CAPC       0       13-3.0AMC       0    280168-8.VRED       26-2
15LIM     9000000.CAPC       0       13-3.0AMC       0    280168-7.VRED       26-2
16LIM     9000000.CAPC       0       13-3.0AMC       0    280168-8.VRED       26-2
17LIM     5900000.CAPC     3000       0+0.0AMC   35000     10522-6.VRED
18LIM     2450000.CAPC     3000       0+0.0AMC   35000    177260-7.VRED
19LIM     1450000.CAPC     3000       0+0.0AMC   35000    261448-7.VRED
20LIM           .CAPC      3000    13991-7.0AMC    200         74-7.VRED        1+0
```

TABLE 34. (CONT'D)

21LIM	.CAPC	3000	23045-7	.0APC	200	74-7.[illegible]	1+
22LIM	.CAPC	3000	13991-7	.0APC	200	74-7.[illegible]	1+
23LIM	.CAPC	3000	23045-7	.0APC	200	74-7.[illegible]	1+
24LIM	.CAPC	3000	23045-7	.0APC	200	74-7.[illegible]	1+
25LIM	.CAPC	3000	23045-7	.0APC	200	74-7.[illegible]	1+
26LIM	.CAPC	3000	23045-7	.0APC	200	74-7.[illegible]	1+
27LIM	.CAPC	3000	23045-7	.0APC	200	74-7.[illegible]	1+
LIOLF1	WINTER	0.5					
IDS1							
3							
1	6-3	6-3 2	010	72-6	5	0+0	15-1
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.01	2100000	1400000	900000	266667	1333333	1333333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.02	1750000	1500000	1200000	866667	933333	666667	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.03	1950000	1766667	1666667	1733333	400000	500000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.04	2100000	1966667	2000000	1400000	666667	1200000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.05	1700000	1433333	800000	1466667	1200000	533333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.06	800000	1500000	1466667	1950000	1533333	1133333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.07	2000000	1600000	1733333	1933333	533333	933333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.08	1466667	2633333	2600000	2800000	2666667	2266667	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.09	2100000	1400000	900000	266667	1333333	1333333	
HAUL.FORM.	1	1	1	1	1	3	0
DIST.TO.10	1750000	1500000	1200000	866667	933333	0000800	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.11	1950000	1766667	1666667	1733333	400000	500000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.12	2100000	1966667	2000000	1400000	666667	1200000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.13	1700000	1433333	800000	1466667	1200000	533333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.14	800000	1500000	1466667	1950000	1533333	1133333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.15	2000000	1600000	1733333	1933333	533333	933333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.16	1466667	2633333	2600000	2800000	2666667	2266667	
HAUL.FORM.	1	3	1	1	1	1	0
DIST.TO.17	1133333	0003000	1600000	1700000	1600000	1266667	
HAUL.FORM.	1	1	3	1	1	1	0
DIST.TO.18	1866667	1066667	0000000	1250000	1600000	1266667	
HAUL.FORM.	1	1	1	1	1	3	0
DIST.TO.19	1650000	1333333	1066667	1066667	600000	0000000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.20	2100000	1400000	900000	266667	1333333	1333333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.21	1750000	1500000	1200000	866667	933333	666667	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.22	1950000	1766667	1666667	1733333	400000	500000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.23	2100000	1966667	2000000	1400000	666667	1200000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.24	1700000	1433333	800000	1466667	1200000	533333	
HAUL.FORM.	1	1	1	1	1	1	

TABLE 34. (CONT'D)

```
DIST.TO.25    800000   1500000   1066667   1950000   1533333   1133333
HAUL.FORM.         1         1         1         1         1         1         0
DIST.TO.26   2000000   1800000   1733333   1933333    533333    933333
HAUL.FORM.         1         1         1         1         1         1         0
DIST.TO.27   1466667   2633333   2600000   2600000   2666667   2266667
HAUL.FORM.         2         1         1         1         1         1         1
HAUL.FORM.         1         0         0         0         0         0         0
DIST.TO.01    250000    733333   1333333    600000   1200000   1750000   1533333
             2450000
HAUL.FORM.         1         2         1         1         1         1         1
HAUL.FORM.         1         0         0         0         0         0         0
DIST.TO.02    733333    250000   1200000    700000    800000   1066667   1533333
             2733333
HAUL.FORM.         1         1         2         1         1         1         1
HAUL.FORM.         1         0         0         0         0         0         0
DIST.TO.03   1333333   1200000    250000    933333   1100000   1266667    533333
             2066667
HAUL.FORM.         1         1         1         2         1         1         1
HAUL.FORM.         1         0         0         0         0         0         0
DIST.TO.04    800000    700000    933333    250000   1000000   1933333   1800000
             2566667
HAUL.FORM.         1         1         1         1         2         1         1
HAUL.FORM.         1         0         0         0         0         0         0
DIST.TO.05   1200000    800000   1100000   1000000    250000   1400000   1466667
             2000000
.AUL.FORM.         1         1         1         1         1         2         1
.AUL.FORM.         1         0         0         0         0         0         0
DIST.TO.06   1750000   1666667   1266667   1933333   1400000    250000    933333
             1266667
.AUL.FORM.         1         1         1         1         1         1         2
.AUL.FORM.         1         0         0         0         0         0         0
DIST.TO.07   1533333   1533333    533333   1800000   1466667    933333    250000
             1600000
.AUL.FORM.         1         1         1         1         1         1         1
.AUL.FORM.         2         0         0         0         0         0         0
DIST.TO.08   2450000   2733333   2066667   2566667   2000000   1266667   1600000
              250000
WEIGHTFAC.   0
                   0                 300                1000
INC        1
INC        2
INC        3
INC        4
INC        5
INC        6
INC        7
INC        8
INC        9
INC       10
INC       11
INC       12
INC       13
INC       14
INC       15
INC       16
INC       00
NOBLOC     0         0
MAXSIZ     6         0         6         6
       END OF FIRST CASE
                   DATA CASE FOR 1980
```

TABLE 34. (CONT'D)

```
|SOUR100654|00000SOUR2|0019770000|SOUR300110|00000SOUR4|0004155000|SOUR500032|10000     |
|SOUR600079|65000     |          |          |          |          |          |          |
|01LIM00015|50000.CAPC|         0|       0+0|.0ANC     |    0     |  0+0.VRED|          |
|02     200|00000.CAPC|         0|      35-4|.0ANC     |    0     | 15-4.VRED|          |
|03   60021|50000.CAPC|         0|       0+0|.0ANC     |    0     |  0+0.VRED|          |
|04     200|00000.CAPC|         0|      35-4|.0ANC     |    0     | 15-4.VRED|          |
|05     200|00000.CAPC|         0|      35-4|.0ANC     |    0     | 15-4.VRED|          |
|06LIM  200|00000.CAPC|         0|      35-4|.0ANC     |    0     | 15-4.VRED|          |
|07LIM  200|00000.CAPC|         0|      35-4|.0ANC     |    0     | 15-4.VRED|          |
|08LIM  200|00000.CAPC|         0|      35-4|.0ANC     |    0     | 15-4.VRED|          |
|09LIM00025|60000.CAPC|         0|00052222-7|.0ANC     |    0     |468-8.VRED|      26-2|
|10LIM00090|00000.CAPC|         0|      13-3|.0ANC     |    0  280|468-8.VRED|      26-2|
|11LIM00035|50000.CAPC|         0|   52222-7|.0ANC     |    0     |468-8.VRED|      26-2|
|12LIM   90|00000.CAPC|         0|      13-3|.0ANC     |    0  280|168-8.VRED|      26-2|
|13LIM   90|00000.CAPC|         0|      13-3|.0ANC     |    0  280|168-8.VRED|      26-2|
|14LIM   90|00000.CAPC|         0|      13-3|.0ANC     |    0  280|168-8.VRED|      26-2|
|15LIM   90|00000.CAPC|         0|      13-3|.0ANC     |    0  280|168-8.VRED|      26-2|
|16LIM   90|00000.CAPC|         0|      13-3|.0ANC     |    0  280|468-8.VRED|      26-2|
|17LIM   88|50000.CAPC|      3000|       0+0|.0ANC     |35000   10|522-6.VRED|          |
|18LIM   36|75000.CAPC|      3000|       0+0|.0ANC     |35000  177|288-7.VRED|          |
|19LIM   27|00000.CAPC|      3000|       0+0|.0ANC     |35000  261|446-7.VRED|          |
|20LIM  270|00000.CAPC|      3000|   13991-7|.0ANC     |   200    | 74-7.VRED|       1+0|
|21LIM  270|00000.CAPC|      3000|   23045-7|.0ANC     |   200    | 74-7.VRED|       1+0|
|22LIM  270|00000.CAPC|      3000|   13991-7|.0ANC     |   200    | 74-7.VRED|       1+0|
|23LIM  270|00000.CAPC|      3000|   13991-7|.0ANC     |   200    | 74-7.VRED|       1+0|
|24LIM  270|00000.CAPC|      3000|   13991-7|.0ANC     |   200    | 74-7.VRED|       1+0|
|25LIM  270|00000.CAPC|      3000|   13991-7|.0ANC     |   200    | 74-7.VRED|       1+0|
|26LIM  270|00000.CAPC|      3000|   13991-7|.0ANC     |   200    | 74-7.VRED|       1+0|
|27LIM  270|00000.CAPC|      3000|   13991-7|.0ANC     |   200    | 74-7.VRED|       1+0|
|LIQLF1    |  WINTER  |0.5       |          |          |          |          |          |
|IDST      |          |          |          |          |          |          |          |
|    3     |          |          |          |          |          |          |          |
|    1     |  6-3     |  6-3    2|       0+0|      72-6|  3       |  0+0     |15-1      |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.01|   2100000|   1400000|    900000|    266667|   1333333|   1333333|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.02|   1750000|   1500000|   1200000|    866667|    933333|    666667|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.03|   1950000|   1766667|   1666667|   1733333|    400000|    500000|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.04|   2100000|   1966667|   2000000|   1400000|    666667|   1200000|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.05|   1700000|   1433333|    800000|   1466667|   1200000|    533333|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.06|    800000|   1500000|   1466667|   1950000|   1533333|   1133333|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.07|   2000000|   1800000|   1733333|   1933333|    533333|    933333|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.08|   1466667|   2633333|   2600000|   2600000|   2666667|   2266667|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.09|   2100000|   1400000|    900000|    266667|   1333333|   1333333|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         3|         0|
|DIST.TO.10|   1750000|   1500000|   1200000|    866667|    933333|    666667|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.11|   1950000|   1766667|   1666667|   1733333|    400000|    500000|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.12|   2100000|   1966667|   2000000|   1400000|    666667|   1200000|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
|DIST.TO.13|   1700000|   1433333|    800000|   1466667|   1200000|    533333|          |
|HAUL.FORM.|         1|         1|         1|         1|         1|         1|         0|
```

TABLE 34. (CONT'D)

DIST.TO.14	800000	1500000	1466667	1950000	1533333	1133333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.15	2000000	1800000	1733333	1933333	533333	933333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.16	1466667	2633333	2600000	2800000	2666667	2266667	
HAUL.FORM.	1	3	1	1	1	1	0
DIST.TO.17	1133333	0003000	1000000	1700000	1600000	1266667	
HAUL.FORM.	1	1	3	1	1	1	0
DIST.TO.18	1866667	1066667	0000000	1250000	1600000	1066667	
HAUL.FORM.	1	1	1	1	1	3	0
DIST.TO.19	1650000	1333333	1066667	1466667	600000	0000000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.20	2100000	1400000	900000	266667	1333333	1333333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.21	1750000	1500000	1200000	866667	933333	666667	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.22	1950000	1766667	1666667	1733333	400000	500000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.23	2100000	1966667	2000000	1400000	666667	1200000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.24	1700000	1433333	800000	1466667	1200000	533333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.25	800000	1500000	1466667	1950000	1533333	1133333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.26	2000000	1800000	1733333	1933333	533333	933333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.27	1466667	2633333	2600000	2800000	2666667	2266667	
HAUL.FORM.	2	1	1	1	1	1	1
HAUL.FORM.	1	0	0	0	0	0	0
DIST.TO.01	250000	733333	1333333	800000	1200000	1750000	1533333
	2450000						
HAUL.FORM.	1	2	1	1	1	1	1
HAUL.FORM.	1	0	0	0	0	0	0
DIST.TO.02	733333	250000	1200000	700000	800000	1666667	1533333
	2733333						
HAUL.FORM.	1	1	2	1	1	1	1
HAUL.FORM.	1	0	0	0	0	0	0
DIST.TO.03	1333333	1200000	250000	933333	1100000	1266667	533333
	2066667						
HAUL.FORM.	1	1	1	2	1	1	1
HAUL.FORM.	1	0	0	0	0	0	0
DIST.TO.04	800000	700000	933333	250000	1000000	1933333	1500000
	2566667						
HAUL.FORM.	1	1	1	1	2	1	1
HAUL.FORM.	1	0	0	0	0	0	0
DIST.TO.05	1200000	800000	1100000	1000000	250000	1400000	1466667
	2000000						
HAUL.FORM.	1	1	1	1	1	2	1
.AUL.FORM.	1	0	0	0	0	0	0
DIST.TO.06	1750000	1666667	1266667	1933333	1400000	250000	933333
	1266667						
.AUL.FORM.	1	1	1	1	1	1	2
.AUL.FORM.	1	0	0	0	0	0	0
DIST.TO.07	1533333	1533333	533333	1300000	1466667	933333	250000
	1600000						
.AUL.FORM.	1	1	1	1	1	1	1
.AUL.FORM.	2	0	0	0	0	0	0
DIST.TO.08	2450000	2733333	2066667	2566667	2000000	1266667	1600000
	250000						
WEIGHTFAC.	0						

TABLE 34. (CONT'D)

```
                   0                 300                1000
INC      1
INC      2
INC      3
INC      4
INC      5
INC      6
INC      7
INC      8
INC      9
INC     10
INC     11
INC     12
INC     13
INC     14
INC     15
INC     16
INC     00
NOBLOC   0         0
MAXSIZ   6         0         6         6
      END OF SECOND CASE
                  DATA CASE FOR 1990
SOUR10006900000SOUR20024525000SOUR30014250000SOUR40004995000SOUR50000425000
SOUR60009720000
01LIM0001550000.CAPC         0       0+0.0AMC        0        0+0.VRED
02     20000000.CAPC         0      35-4.0AMC        0       15-4.VRED
03   0002150000.CAPC         0       0+0.0AMC        0        0+0.VRED
04     20000000.CAPC         0      35-4.0AMC        0       15-4.VRED
05     20000000.CAPC         0      35-4.0AMC        0       15-4.VRED
06LIM  20000000.CAPC         0      35-4.0AMC        0       15-4.VRED
07LIM  20000000.CAPC         0      35-4.0AMC        0       15-4.VRED
08LIM  20000000.CAPC         0      35-4.0AMC        0       15-4.VRED
09LIM0002580000.CAPC         000052222-7.0AMC        0      468-8.VRED          26-2
10LIM0009000000.CAPC         0      13-3.0AMC        0   280468-6.VRED          26-2
11LIM0003560000.CAPC         0   52222-7.0AMC        0      468-8.VRED          26-2
12LIM   9000000.CAPC         0      13-3.0AMC        0   280468-8.VRED          26-2
13LIM   9000000.CAPC         0      13-3.0AMC        0   280468-6.VRED          26-2
14LIM   9000000.CAPC         0      13-3.0AMC        0   280468-8.VRED          26-2
15LIM   9000000.CAPC         0      13-3.0AMC        0   280468-6.VRED          26-2
16LIM   9000000.CAPC         0      13-3.0AMC        0   280468-8.VRED          26-2
17LIM  11800000.CAPC      3000       0+0.0AMC    35000   10522-6.VRED
18LIM   4900000.CAPC      3000       0+0.0AMC    35000  177288-7.VRED
19LIM   3600000.CAPC      3000       0+0.0AMC    35000  261448-7.VRED
20LIM  27000000.CAPC      3000   13991-7.0AMC      200       74-7.VRED           1+0
21LIM  27000000.CAPC      3000   23045-7.0AMC      200       74-7.VRED           1+0
22LIM  27000000.CAPC      3000   13991-7.0AMC      200       74-7.VRED           1+0
23LIM  27000000.CAPC      3000   13991-7.0AMC      200       74-7.VRED           1+0
24LIM  27000000.CAPC      3000   13991-7.0AMC      200       74-7.VRED           1+0
25LIM  27000000.CAPC      3000   13991-7.0AMC      200       74-7.VRED           1+0
26LIM  27000000.CAPC      3000   13991-7.0AMC      200       74-7.VRED           1+0
27LIM  27000000.CAPC      3000   13991-7.0AMC      200       74-7.VRED           1+0
LIQLF1      WINTER  0.5
IDS1
    3
    1        6-3       6-3   2       0+0      72-6     3         0+0       15-1
HAUL.FORM.         1         1         1         1         1         1             0
DIST.TO.01   2100000   1400000    900000    266667   1333333   1333333
HAUL.FORM.         1         1         1         1         1         1             0
DIST.TO.02   1750000   1500000   1200000    866667    933333    666667
HAUL.FORM.         1         1         1         1         1         1             0
```

TABLE 34. (CONT'D)

DIST.TO.03	1950000	1766667	1666667	1733333	400000	500000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.04	2100000	1966667	2000000	1400000	666667	1200000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.05	1700000	1433333	800000	1466667	1200000	533333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.06	800000	1500000	1466667	1950000	1533333	1133333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.07	2000000	1800000	1733333	1933333	533333	933333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.08	1466667	2633333	2600000	2800000	2666667	2266667	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.09	2100000	1400000	900000	266667	1333333	1333333	
HAUL.FORM.	1	1	1	1	1	3	0
DIST.TO.10	1750000	1500000	1200000	866667	933333	0600600	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.11	1950000	1766667	1666667	1733333	400000	500000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.12	2100000	1966667	2000000	1400000	666667	1200000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.13	1700000	1433333	800000	1466667	1200000	533333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.14	800000	1500000	1466667	1950000	1533333	1133333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.15	2000000	1800000	1733333	1933333	533333	933333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.16	1466667	2633333	2600000	2800000	2666667	2266667	
HAUL.FORM.	1	3	1	1	1	1	0
DIST.TO.17	1133333	0003000	1000000	1700000	1600000	1266667	
HAUL.FORM.	1	1	3	1	1	1	0
DIST.TO.18	1866667	1066667	0000000	1250000	1600000	1066667	
HAUL.FORM.	1	1	1	1	1	3	0
DIST.TO.19	1650000	1333333	1066667	1466667	600000	0000000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.20	2100000	1400000	900000	266667	1333333	1333333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.21	1750000	1500000	1200000	866667	933333	666667	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.22	1950000	1766667	1666667	1733333	400000	500000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.23	2100000	1966667	2000000	1400000	666667	1200000	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.24	1700000	1433333	800000	1466667	1200000	533333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.25	800000	1500000	1466667	1950000	1533333	1133333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.26	2000000	1800000	1733333	1933333	533333	933333	
HAUL.FORM.	1	1	1	1	1	1	0
DIST.TO.27	1466667	2633333	2600000	2800000	2666667	2266667	
HAUL.FORM.	2	1	1	1	1	1	1
HAUL.FORM.	1	0	0	0	0	0	0
DIST.TO.01	250000	733333	1333333	600000	1200000	1750000	1533333
.	2450000						
HAUL.FORM.	1	2	1	1	1	1	1
HAUL.FORM.	1	0	0	0	0	0	0
DIST.TO.02	733333	250000	1200000	700000	800000	1066667	1533333
	2733333						
HAUL.FORM.	1	1	2	1	1	1	1
HAUL.FORM.	1	0	0	0	0	0	0
DIST.TO.03	1333333	1200000	250000	933333	1100000	1266667	533333

TABLE 34. (CONT'D)

```
           |  2066667|
HAUL.FORM. |        1|        1|        1|        2|        1|        1|        1|
HAUL.FORM. |        1|        0|        0|        0|        0|        0|        0|
DIST.TO.04 |   800000|   700000|   933333|   250000|  1000000|  1933333|  1600000|
           |  2566667|
HAUL.FORM. |        1|        1|        1|        1|        2|        1|        1|
HAUL.FORM. |        1|        0|        0|        0|        0|        0|        0|
DIST.TO.05 |  1200000|   800000|  1100000|  1000000|   250000|  1400000|  1466667|
           |  2000000|
.AUL.FORM. |        1|        1|        1|        1|        1|        2|        1|
.AUL.FORM. |        1|        0|        0|        0|        0|        0|        0|
DIST.TO.06 |  1750000|  1666667|  1266667|  1933333|  1400000|   250000|   933333|
           |  1266667|
.AUL.FORM. |        1|        1|        1|        1|        1|        1|        2|
.AUL.FORM. |        1|        0|        0|        0|        0|        0|        0|
DIST.TO.07 |  1533333|  1533333|   533333|  1800000|  1466667|   933333|   250000|
           |  1600000|
.AUL.FORM. |        1|        1|        1|        1|        1|        1|        1|
.AUL.FORM. |        2|        0|        0|        0|        0|        0|        0|
DIST.TO.06 |  2450000|  2733333|  2066667|  2566667|  2000000|  1266667|  1600000|
           |   250000|
WEIGHTFAC. | 0
           |        0|         |      300|         |     1000|
INC       1|
INC       2|
INC       3|
INC       4|
INC       5|
INC       6|
INC       7|
INC       8|
INC       9|
INC      10|
INC      11|
INC      12|
INC      13|
INC      14|
INC      15|
INC      16|
INC      00|
NOBLOC    0|        0|
MAXSIZ    6|        0|        6|        6|
====    END OF LAST CASE
```

APPENDIX V

DETAILS OF ALL02

APPENDIX V

DETAILS OF ALL02

V.1 Block Data

The block data subprogram, as it appears in the listing in Appendix VI, is duplicated in Table 35. Its main purpose is to let the user define INF and the I/O file unit numbers IR1, IW1, IR2 and IW2 without putting these in the input data deck, since they rarely change for a given user.

TABLE 35. THE BLOCK DATA SUBPROGRAM IN ALL02

```
 BLOCKDATA                                                              08270000
 COMMON/LAYDAT/NN(10),IR1,IW1,IR2,IW2,ILP1(30),ILP2(30),JLP(30),LFP08280000
*P(30),JOUT(30),IH(8)/INLARB/INLARS(1435)/INSMAB/INSMAS(123)/ACONVB08290000
*/ACONVS(40)/REALB/REALS(731)/LOGICB/LOGICS(1024)                       08300000
 INTEGERACONVS                                                          08310000
 LOGICALLOGICS                                                          08320000
 DATALOGICS/1024*.FALSE./,INSMAS/123*0/,INLARS/1435*999999999/,ACON08330000
*VS/40*4HDASH/,REALS/731*0.0/,IR1,IW1,IR2,IW2/5,6,8,9/,IH/4H SOU,4H08340000
*RCE ,4H STO,4HRAGE,4H  TO,4HTAL ,4HAM T,4HO LF/                        08350000
 END                                                                    08360000
```

The subprogram also serves to store initial values in the data strings LOGICS, INSMAS, INLARS, ACONVS and REALS, so that no part of them could be undefined when a data dump on unit IW2 occurs. Each of these strings is equivalent to a common block containing several variables used in the execution of the program. The block data subprogram initializes all members of INLARS with the value desired for INF (see line 08330000, where we have used the value 999999999). Since INF is a variable embedded in INLARS, it receives its definition in this way. Some other variables which must equal INF at the beginning of the execution are incidentally initialized in this way since they are also embedded in INLARS.

The variables IR1, IW1, IR2 and IW2 are initialized explicitly and simply (see line 08340000, where we have used the values 5, 6, 8 and 9, respectively).

The subprogram has one final purpose: to define the 8-element string IH which subroutine LAYOUT manipulates to form headings when printing out tables (see lines 08340000 and 08350000). This need never be modified by the user.

V.2 Array Dimensions

The dimensions of the following arrays will always be the same: main program - TITLE (20), MFC1 (4), IH (8), MAXSIZ (4), MFC (4), COND (4); additional array in subroutine START - ISAY (18); additional array in subroutine LAYOUT - IH (20).

The other arrays have dimensions that are dependent on the problem size. For brevity, let:

s = number of sources
f = number of facilities of all types
e = number of summer dead-end facilities
p = number of all-year intermediate facilities
d = number of all-year dead-end facilities
h = number of winter intermediate facilities
u = s + h + e
v = maximum of e or d + p
t = maximum of s, h or p
r = maximum of 4t or 2 s + 2f
a = number of haulage formulas
m = maximum number of solutions stored (=MAXSOL)

Then the minimum dimensions of the other arrays are as follows: main program -

W(r), OAMF(f), KF(f), JCOF(t), HAULF(a) HAULV(a);
NL(uxv), INTG(u), LISTU(u), LS(uxv), INTR(v), LISTV(v), LSV(v), A(u), B(v), C(u,v), X(u,v), KWC(u,v);
ILP1(f), ILP2(f), JLP(f), LFPP(f), JOUT(f)
NOTUSE(f), O(m), UMINP(f), KMINP(f);
CONF(f), CAP(f), CTRANS(s,e), CTRANL(s,e), CTRANP(s,d), Q(s), IDSOL(m), ZSOL(m), MTWO(f), BAR(f), OLDBAR(f), KTRANS(s,f), KTRANP(s,d):
NAVA (f), OLNAVA(f), IYP(f);
NAMSRC(s), NAMFAC(f);
DISTNS(s,f), DISTNL(s,e), DISTNP(s,d), VRED(f);
NOBLOC(fxf), INC(f), MSET(f), SUPF(f);

additional arrays in subroutine START -
Y(4,t), XS(s), YS(s), XF(f), YF(f), OAMV(f), CONV(f).

Related to these dimension requirements are the equivalence statements in subroutine START (see lines 08660000, 08670000). Those which depend on problem size are all concerned with the vector W, which is used in the program for the temporary storage of the matrix Y, and at another point for the two vectors CONV and OAMV, and at another point for the four vectors XS, YS, YF and YS. Care must be taken that the first f elements of CONV do not overlap with the first f elements of OAMV although these two vectors can be located anywhere within W. Similarly, overlapping must not occur among the first s elements of XS, the first s of YS, the first f of YF, and the first f of XF, although these four vectors can be located anywhere within W.

The coincidence of the first element of Y with the first element of W is imperative for correct functioning of the program; this part of the equivalence statement must not be changed.

V.3 The Scaling Routine

The main purpose of the scaling routine is to ensure that the total system cost of every possible solution considered by the program is less than INF. The total system cost referred to is that used internally by the program. This may be much larger than the actual number because the program multiplies all distribution cost coefficients by 10^7 so that it can handle them as integers.

Let I = the total source production

J = the maximum distribution cost coefficient after multiplication by 10^7

K = the sum of all facility fixed charges.

Then the following is the upper bound used by the program for the internal total system cost of any solution:

$$\frac{I}{ISCUAN} \times \frac{J}{ISCOEF} + \frac{K}{ISCUAN \times ISCOEF \times 10^{-7}}, \qquad (16)$$

where ISCUAN and ISCOEF are the factors by which sludge volumes and distribution cost coefficients, respectively, are scaled down. Thus, the following inequality is used by the program to determine ISCUAN and ISCOEF:

$$\mathrm{ISCUAN} \times \mathrm{ISCOEF} \geq \frac{I \times J + K}{\mathrm{INF} \times 10^{-7}} \qquad (17)$$

Two further considerations for the determination of these factors arise from the computations that occur in the program. The parameter WINTER is changed into the ratio of two integers, the second of which (the denomination) is called IWFAC. At one point in the program the cost coefficients and source outputs are multiplied by IWFAC. Thus, the following inequalities enter into the scaling routine:

$$X \geq J \times \mathrm{IWFAC}/\mathrm{INF} \qquad (18)$$

and

$$Y \geq L \times \mathrm{IWFAC}/\mathrm{INF}, \qquad (19)$$

where L = the maximum source output.

The number IWFAC is not preset in the program but is determined simultaneously with ISCUAN and ISCOEF. The objective is to get ISCUAN and ISCOEF as small and as nearly the same as possible; but the smaller they are, the smaller IWFAC must be. It is desirable to have IWFAC at least 100, and as large as possible up to about 100,000 so that WINTER can be accurately expressed in terms of a ratio of integers.

Therefore, the scaling routine starts with IWFAC = 100,000 and solves the above three inequalities (17, 18, and 19) so as to get ISCUAN and ISCOEF as small and as nearly the same as possible*; if they do not turn out to be small enough, IWFAC is decreased and the process is repeated. The criterion that determines when ISCUAN and ISCOEF are small enough is that both J/ISCOEF and L/ISCUAN must be over 10,000; that is, the routine endeavours to obtain at least four significant digits in the scaled integers that the program works with. If, however, IWFAC has been decreased repeatedly without satisfying this criterion, so that its value has become less than 100, then the criterion is ignored and the current values of ISCUAN and ISCOEF are accepted.

The final values of ISCUAN, ISCOEF and IWFAC are rounded up or down to obtain numbers that are integral powers of 10 in order to minimize the round-off errors that result from the computations involving them.

The scaling routine, as shown in the listing in Appendix VI (see lines 1062000 to 1084000), is conservative in that it does not use INF but rather INF/10. This is done because, no matter how much a program is tested, there may yet be occasions when computations could produce overflow. This safety factor could be removed, nevertheless, if the user so desired.

---

* In effect, the sum of ISCUAN and ISCOEF is minimized subject to the constraints imposed by the inequalities.

V.4 Linear Programming

Subroutine LINPRO is our FORTRAN version of the C.A.C.M. Algorithm 293, which is in Algol. This algorithm is a most efficiently programmed implementation of the primal-dual "transportation" algorithm of G. Hadley (Hadley, 1962). It uses lists of pointers to monitor the active elements of the sparse matrices involved.

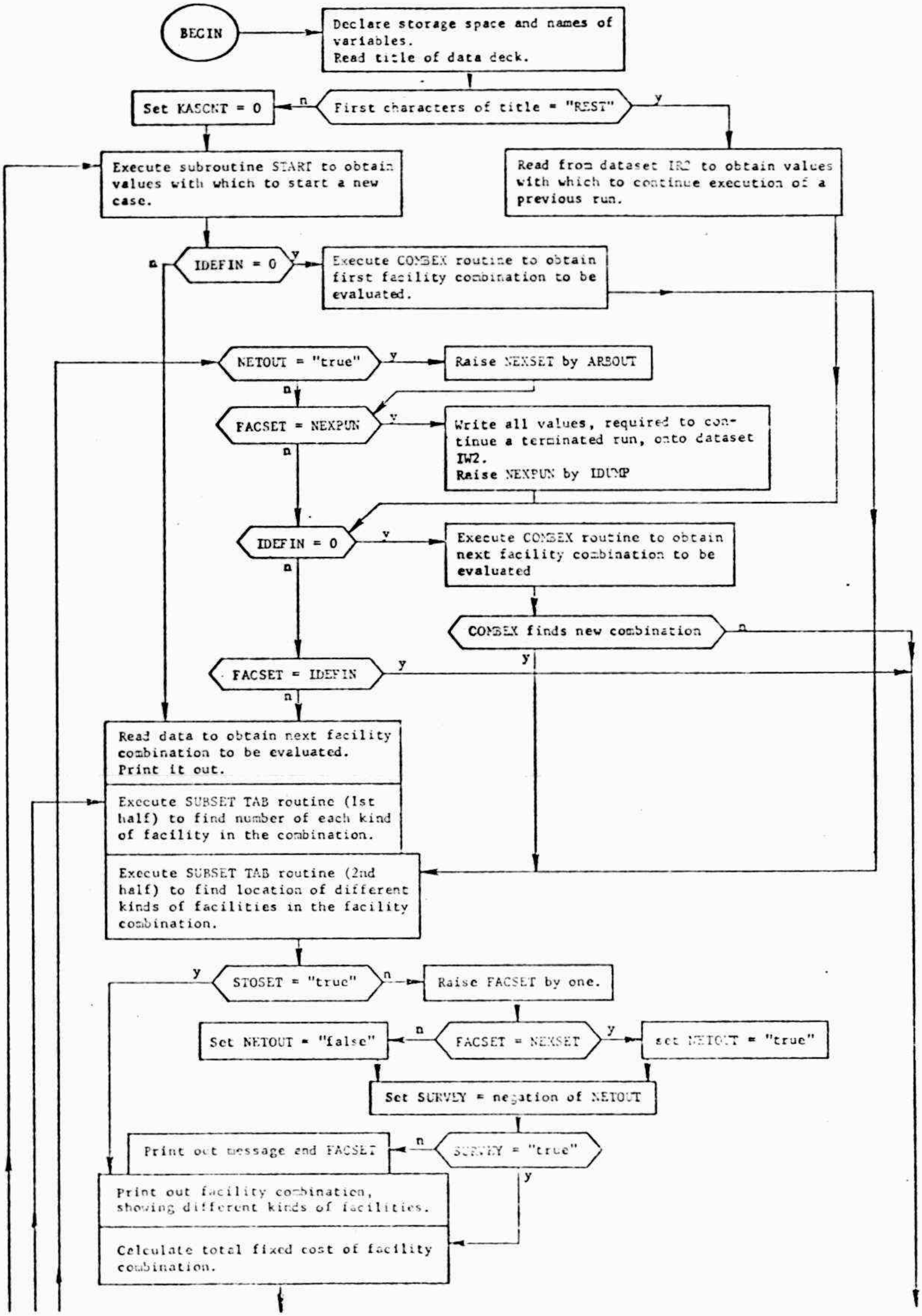
Subroutine LINPRO omits the operations by which the dual objective function may be built up from zero, since weighted cost coefficients may often be used instead of the real coefficients for the optimization. The cost of the optimized solution is calculated in the main program using the real cost coefficients.

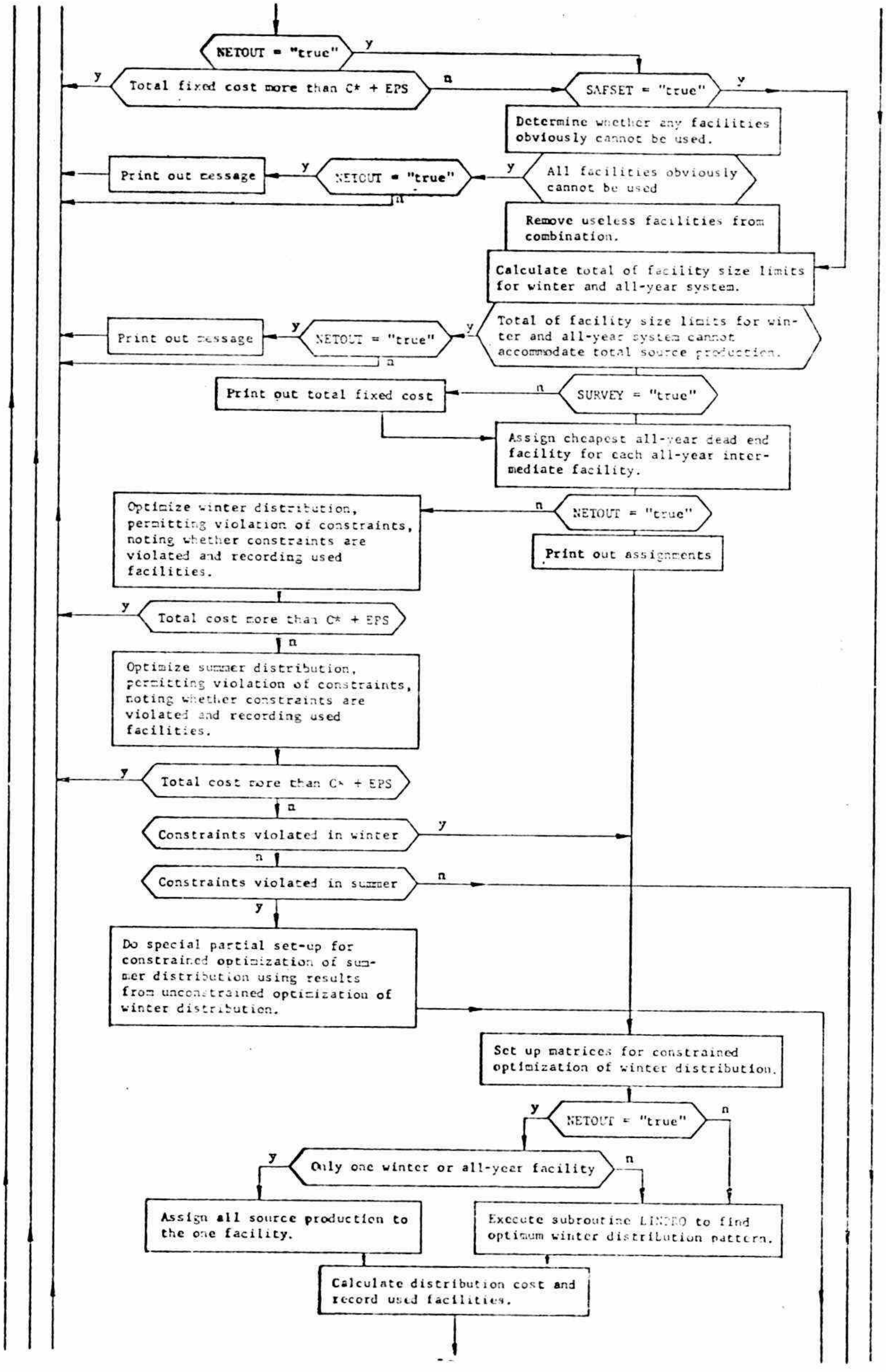
V.5 Flowcharts

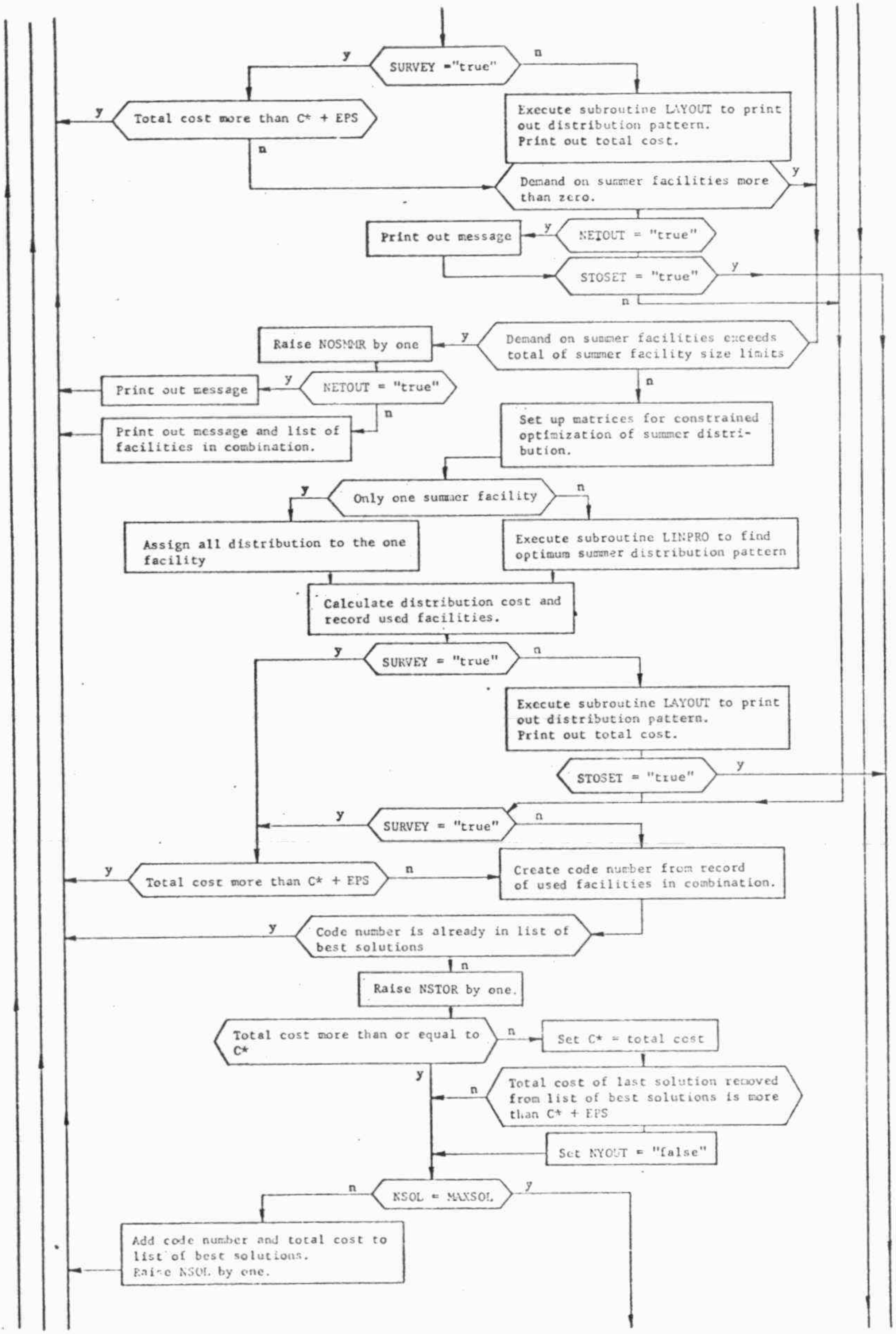
Figures 54 to 57 give detailed flowcharts for all parts of ALLO2 except the very small subprograms which are easily understood without flowcharts.

These charts are designed to give the reader a complete understanding of the program when read in conjunction with the listing in Appendix VI.

FIGURE 54. MAIN PROGRAM FLOWCHART


BEGIN
Declare storage space and names of variables.
Read title of data deck.
First characters of title = "REST"
n
y
Set KASCNT = 0
Execute subroutine START to obtain values with which to start a new case.
Read from dataset IR2 to obtain values with which to continue execution of a previous run.
IDEFIN = 0
n
y
Execute COMBEX routine to obtain first facility combination to be evaluated.
NETOUT = "true"
y
n
Raise NEXSET by ARBOUT
FACSET = NEXPUN
y
n
Write all values, required to continue a terminated run, onto dataset IW2.
Raise NEXPUN by IDUMP
IDEFIN = 0
y
n
Execute COMBEX routine to obtain next facility combination to be evaluated
COMBEX finds new combination
n
y
FACSET = IDEFIN
y
n
Read data to obtain next facility combination to be evaluated.
Print it out.
Execute SUBSET TAB routine (1st half) to find number of each kind of facility in the combination.
Execute SUBSET TAB routine (2nd half) to find location of different kinds of facilities in the facility combination.
STOSET = "true"
y
n
Raise FACSET by one.
Set NETOUT = "false"
n
FACSET = NEXSET
y
set NETOUT = "true"
Set SURVEY = negation of NETOUT
Print out message and FACSET
n
SURVEY = "true"
y
Print out facility combination, showing different kinds of facilities.
Calculate total fixed cost of facility combination.


NETOUT = "true"
y
y
Total fixed cost more than C* + EPS
n
SAFSET = "true"
y
Determine whether any facilities obviously cannot be used.
Print out message
y
NETOUT = "true"
y
All facilities obviously cannot be used
n
Remove useless facilities from combination.
Calculate total of facility size limits for winter and all-year system.
Print out message
y
NETOUT = "true"
y
Total of facility size limits for winter and all-year system cannot accommodate total source production.
n
Print out total fixed cost
n
SURVEY = "true"
Assign cheapest all-year dead end facility for each all-year intermediate facility.
Optimize winter distribution, permitting violation of constraints, noting whether constraints are violated and recording used facilities.
n
NETOUT = "true"
Print out assignments
y
Total cost more than C* + EPS
n
Optimize summer distribution, permitting violation of constraints, noting whether constraints are violated and recording used facilities.
y
Total cost more than C* + EPS
n
Constraints violated in winter
y
n
Constraints violated in summer
n
y
Do special partial set-up for constrained optimization of summer distribution using results from unconstrained optimization of winter distribution.
Set up matrices for constrained optimization of winter distribution.
y
NETOUT = "true"
n
y
Only one winter or all-year facility
n
Assign all source production to the one facility.
Execute subroutine LINPRO to find optimum winter distribution pattern.
Calculate distribution cost and record used facilities.


SURVEY ="true"
y
n
Total cost more than C* + EPS
Execute subroutine LAYOUT to print out distribution pattern. Print out total cost.
Demand on summer facilities more than zero.
Print out message
NETOUT = "true"
STOSET = "true"
Raise NOSMMR by one
Demand on summer facilities exceeds total of summer facility size limits
Print out message
NETOUT = "true"
Print out message and list of facilities in combination.
Set up matrices for constrained optimization of summer distribution.
Only one summer facility
Assign all distribution to the one facility
Execute subroutine LINPRO to find optimum summer distribution pattern
Calculate distribution cost and record used facilities.
SURVEY = "true"
Execute subroutine LAYOUT to print out distribution pattern. Print out total cost.
STOSET = "true"
SURVEY = "true"
Total cost more than C* + EPS
Create code number from record of used facilities in combination.
Code number is already in list of best solutions
Raise NSTOR by one.
Total cost more than or equal to C*
Set C* = total cost
Total cost of last solution removed from list of best solutions is more than C* + EPS
Set NYOUT = "false"
NSOL = MAXSOL
Add code number and total cost to list of best solutions. Raise NSOL by one.

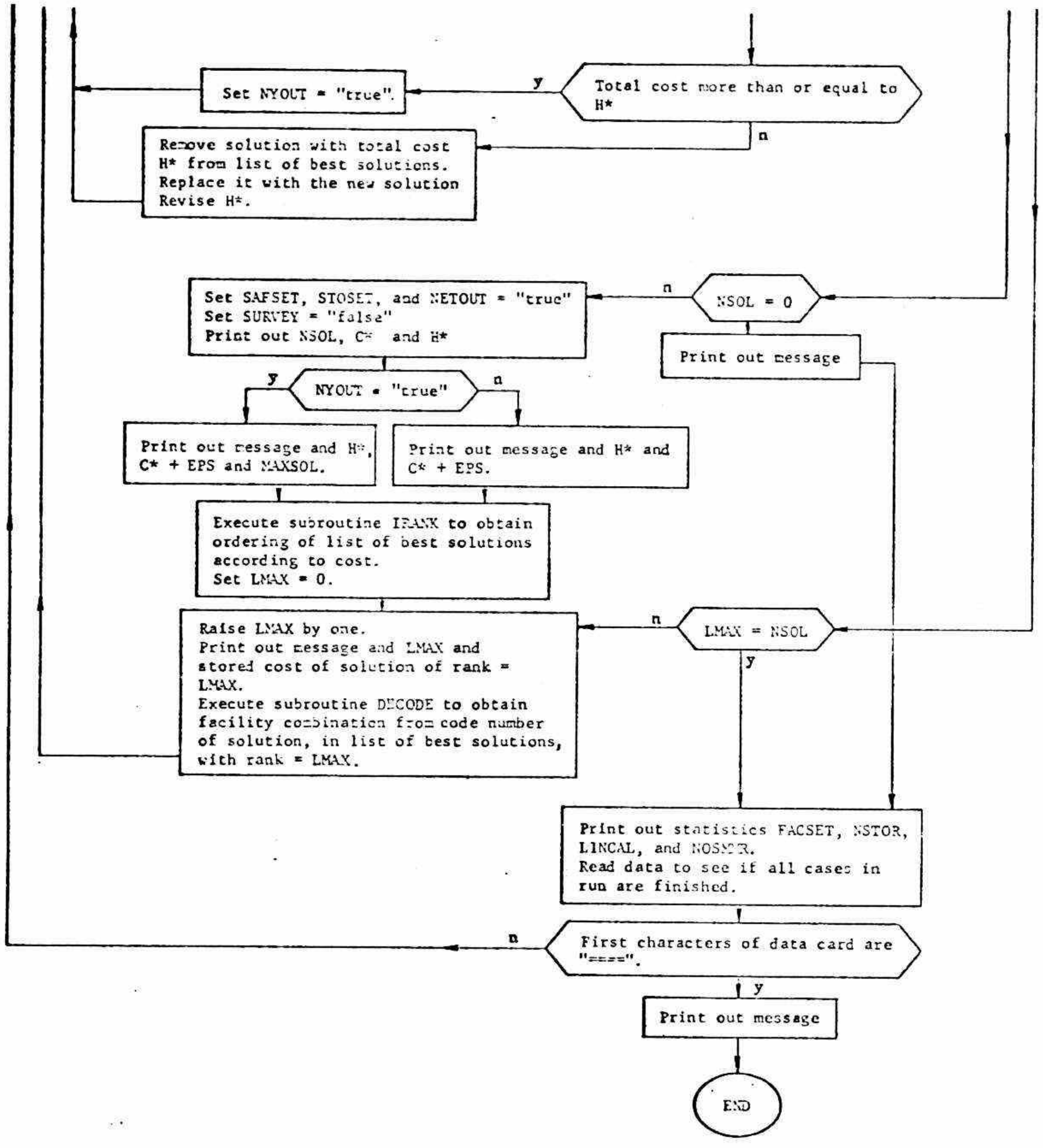
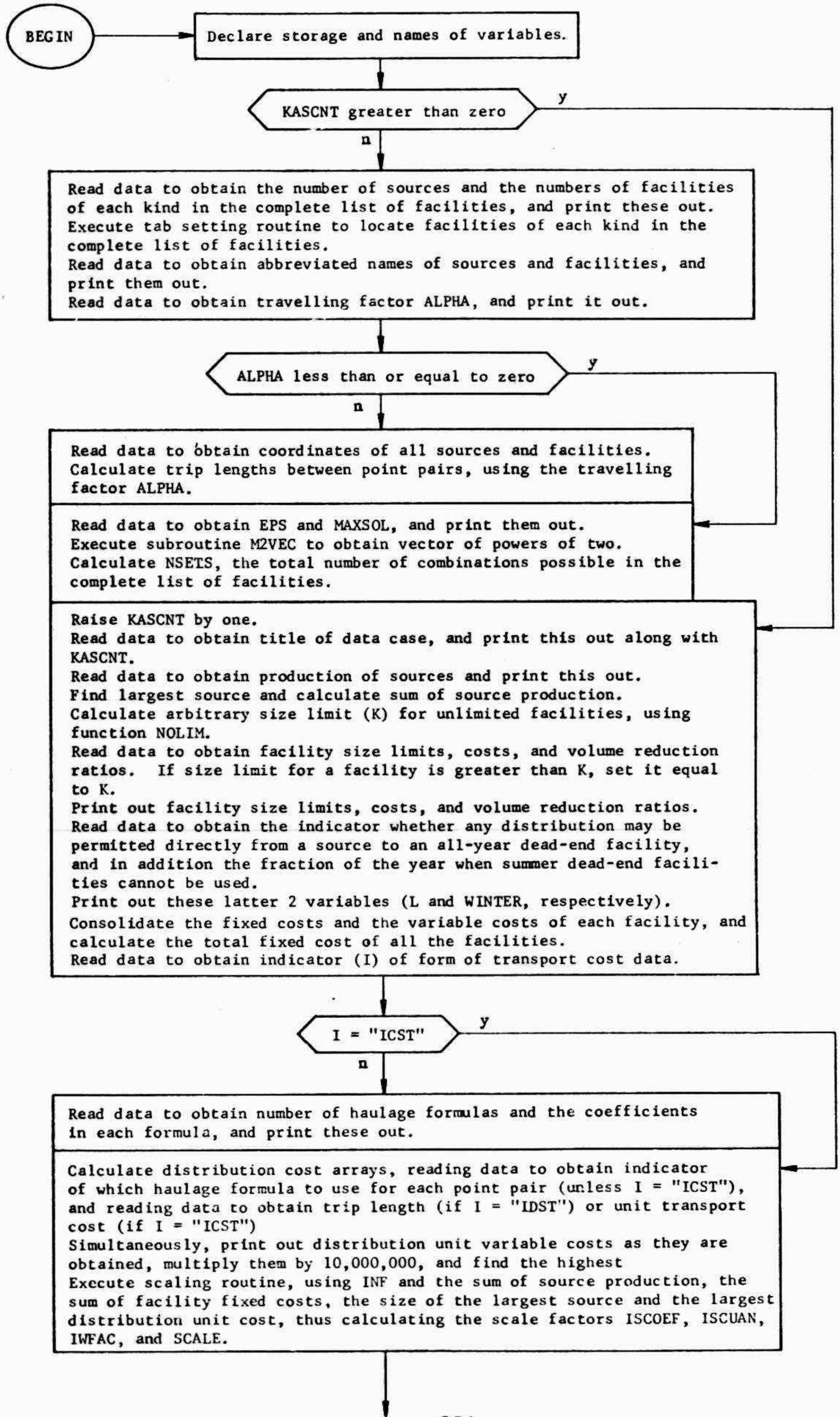

Set NYOUT = "true".
y
Total cost more than or equal to H*
n
Remove solution with total cost H* from list of best solutions. Replace it with the new solution Revise H*.
Set SAFSET, STOSET, and NETOUT = "true" Set SURVEY = "false" Print out NSOL, C* and H*
n
NSOL = 0
Print out message
y
NYOUT = "true"
n
Print out message and H*, C* + EPS and MAXSOL.
Print out message and H* and C* + EPS.
Execute subroutine IRANK to obtain ordering of list of best solutions according to cost. Set LMAX = 0.
Raise LMAX by one. Print out message and LMAX and stored cost of solution of rank = LMAX. Execute subroutine DECODE to obtain facility combination from code number of solution, in list of best solutions, with rank = LMAX.
n
LMAX = NSOL
y
Print out statistics FACSET, NSTOR, LINCAL, and NOSMTR. Read data to see if all cases in run are finished.
n
First characters of data card are "====".
y
Print out message
END

FIGURE 55. **SUBROUTINE** START FLOWCHART



Declare storage and names of variables.

KASCNT greater than zero

Read data to obtain the number of sources and the numbers of facilities of each kind in the complete list of facilities, and print these out.
Execute tab setting routine to locate facilities of each kind in the complete list of facilities.
Read data to obtain abbreviated names of sources and facilities, and print them out.
Read data to obtain travelling factor ALPHA, and print it out.

ALPHA less than or equal to zero

Read data to obtain coordinates of all sources and facilities.
Calculate trip lengths between point pairs, using the travelling factor ALPHA.

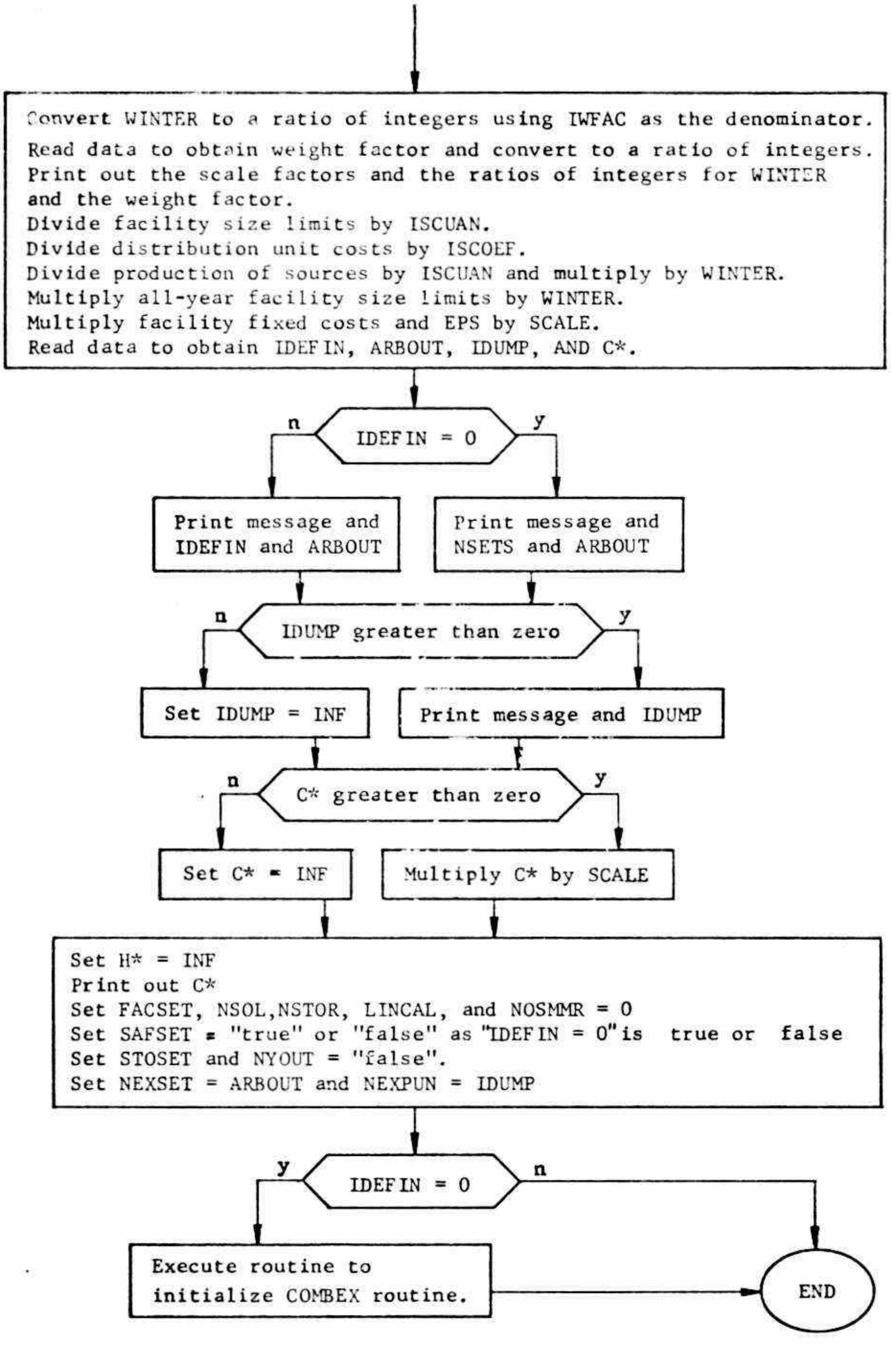
Read data to obtain EPS and MAXSOL, and print them out.
Execute subroutine M2VEC to obtain vector of powers of two.
Calculate NSETS, the total number of combinations possible in the complete list of facilities.

Raise KASCNT by one.
Read data to obtain title of data case, and print this out along with KASCNT.
Read data to obtain production of sources and print this out.
Find largest source and calculate sum of source production.
Calculate arbitrary size limit (K) for unlimited facilities, using function NOLIM.
Read data to obtain facility size limits, costs, and volume reduction ratios. If size limit for a facility is greater than K, set it equal to K.
Print out facility size limits, costs, and volume reduction ratios.
Read data to obtain the indicator whether any distribution may be permitted directly from a source to an all-year dead-end facility, and in addition the fraction of the year when summer dead-end facilities cannot be used.
Print out these latter 2 variables (L and WINTER, respectively).
Consolidate the fixed costs and the variable costs of each facility, and calculate the total fixed cost of all the facilities.
Read data to obtain indicator (I) of form of transport cost data.

I = "ICST"

Read data to obtain number of haulage formulas and the coefficients in each formula, and print these out.

Calculate distribution cost arrays, reading data to obtain indicator of which haulage formula to use for each point pair (unless I = "ICST"), and reading data to obtain trip length (if I = "IDST") or unit transport cost (if I = "ICST")
Simultaneously, print out distribution unit variable costs as they are obtained, multiply them by 10,000,000, and find the highest
Execute scaling routine, using INF and the sum of source production, the sum of facility fixed costs, the size of the largest source and the largest distribution unit cost, thus calculating the scale factors ISCOEF, ISCUAN, IWFAC, and SCALE.



Convert WINTER to a ratio of integers using IWFAC as the denominator.
Read data to obtain weight factor and convert to a ratio of integers.
Print out the scale factors and the ratios of integers for WINTER and the weight factor.
Divide facility size limits by ISCUAN.
Divide distribution unit costs by ISCOEF.
Divide production of sources by ISCUAN and multiply by WINTER.
Multiply all-year facility size limits by WINTER.
Multiply facility fixed costs and EPS by SCALE.
Read data to obtain IDEFIN, ARBOUT, IDUMP, AND C*.

Print message and IDEFIN and ARBOUT

Print message and NSETS and ARBOUT

Set IDUMP = INF

Print message and IDUMP

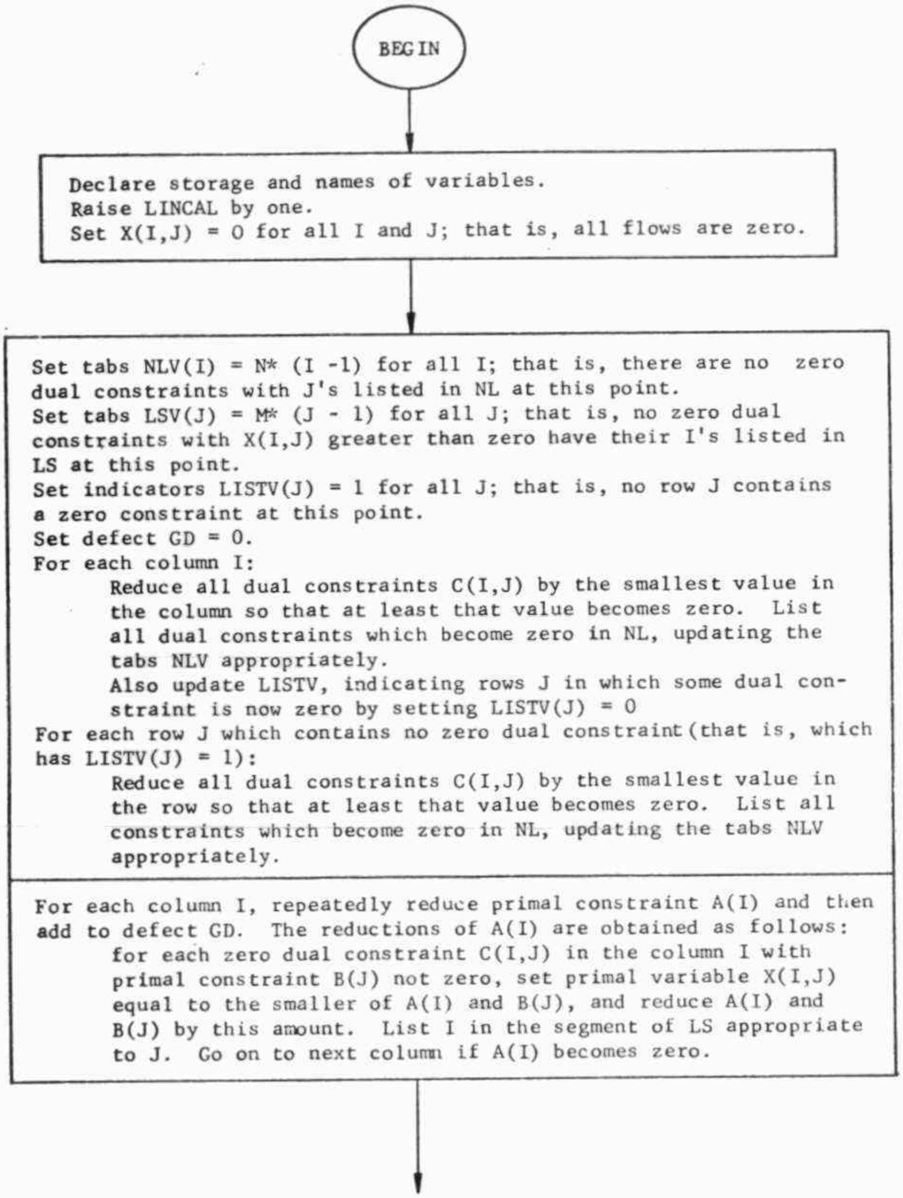
Set C* = INF

Multiply C* by SCALE

Set H* = INF
Print out C*
Set FACSET, NSOL, NSTOR, LINCAL, and NOSMMR = 0
Set SAFSET = "true" or "false" as "IDEFIN = 0" is true or false
Set STOSET and NYOUT = "false".
Set NEXSET = ARBOUT and NEXPUN = IDUMP

Execute routine to initialize COMBEX routine.

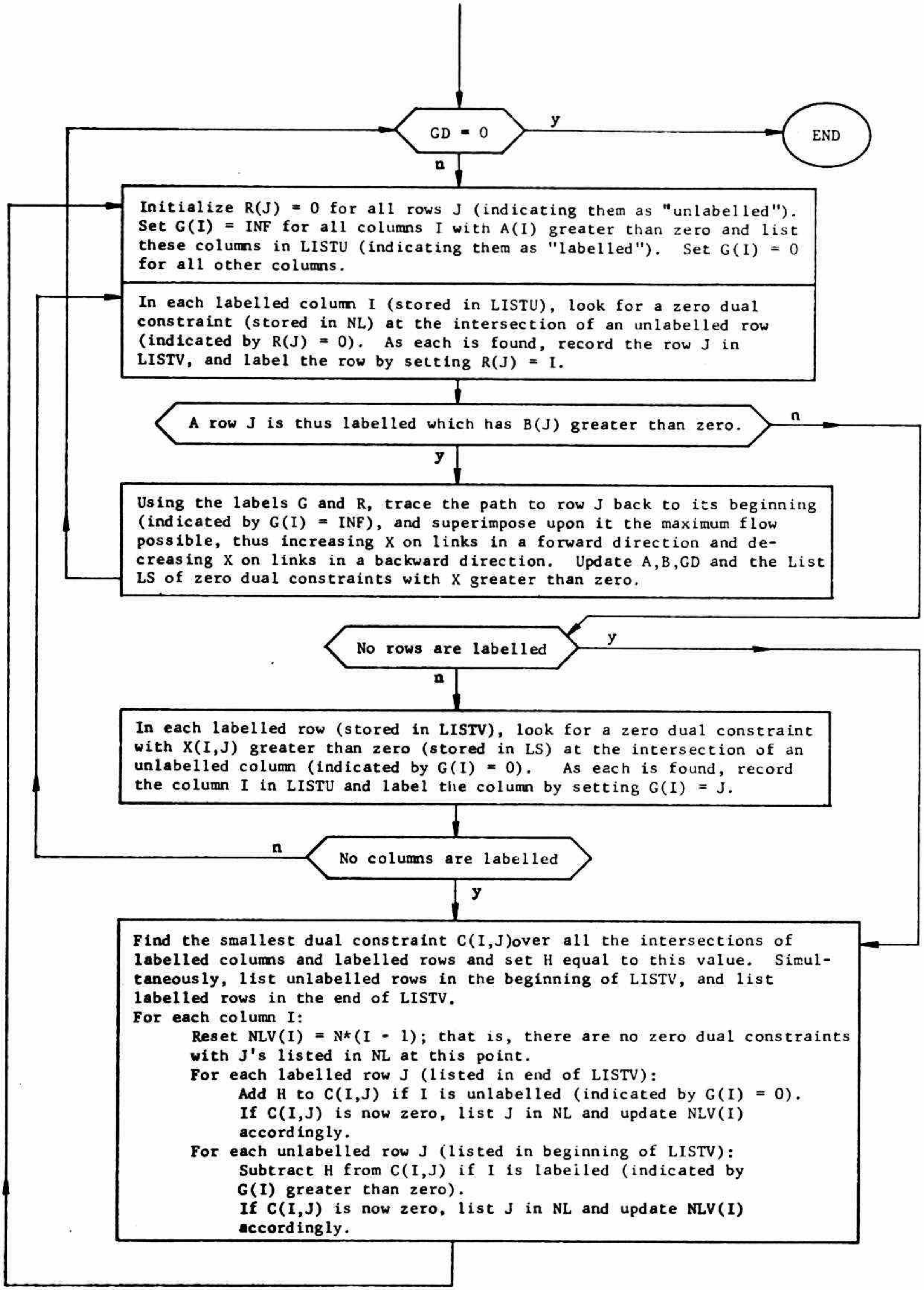
FIGURE 56. SUBROUTINE LINPRO FLOWCHART



Declare storage and names of variables.
Raise LINCAL by one.
Set X(I,J) = 0 for all I and J; that is, all flows are zero.

Set tabs NLV(I) = N* (I -1) for all I; that is, there are no zero dual constraints with J's listed in NL at this point.
Set tabs LSV(J) = M* (J - 1) for all J; that is, no zero dual constraints with X(I,J) greater than zero have their I's listed in LS at this point.
Set indicators LISTV(J) = 1 for all J; that is, no row J contains a zero constraint at this point.
Set defect GD = 0.
For each column I:
    Reduce all dual constraints C(I,J) by the smallest value in the column so that at least that value becomes zero. List all dual constraints which become zero in NL, updating the tabs NLV appropriately.
    Also update LISTV, indicating rows J in which some dual constraint is now zero by setting LISTV(J) = 0
For each row J which contains no zero dual constraint (that is, which has LISTV(J) = 1):
    Reduce all dual constraints C(I,J) by the smallest value in the row so that at least that value becomes zero. List all constraints which become zero in NL, updating the tabs NLV appropriately.

For each column I, repeatedly reduce primal constraint A(I) and then add to defect GD. The reductions of A(I) are obtained as follows:
    for each zero dual constraint C(I,J) in the column I with primal constraint B(J) not zero, set primal variable X(I,J) equal to the smaller of A(I) and B(J), and reduce A(I) and B(J) by this amount. List I in the segment of LS appropriate to J. Go on to next column if A(I) becomes zero.



Initialize R(J) = 0 for all rows J (indicating them as "unlabelled"). Set G(I) = INF for all columns I with A(I) greater than zero and list these columns in LISTU (indicating them as "labelled"). Set G(I) = 0 for all other columns.

In each labelled column I (stored in LISTU), look for a zero dual constraint (stored in NL) at the intersection of an unlabelled row (indicated by R(J) = 0). As each is found, record the row J in LISTV, and label the row by setting R(J) = I.

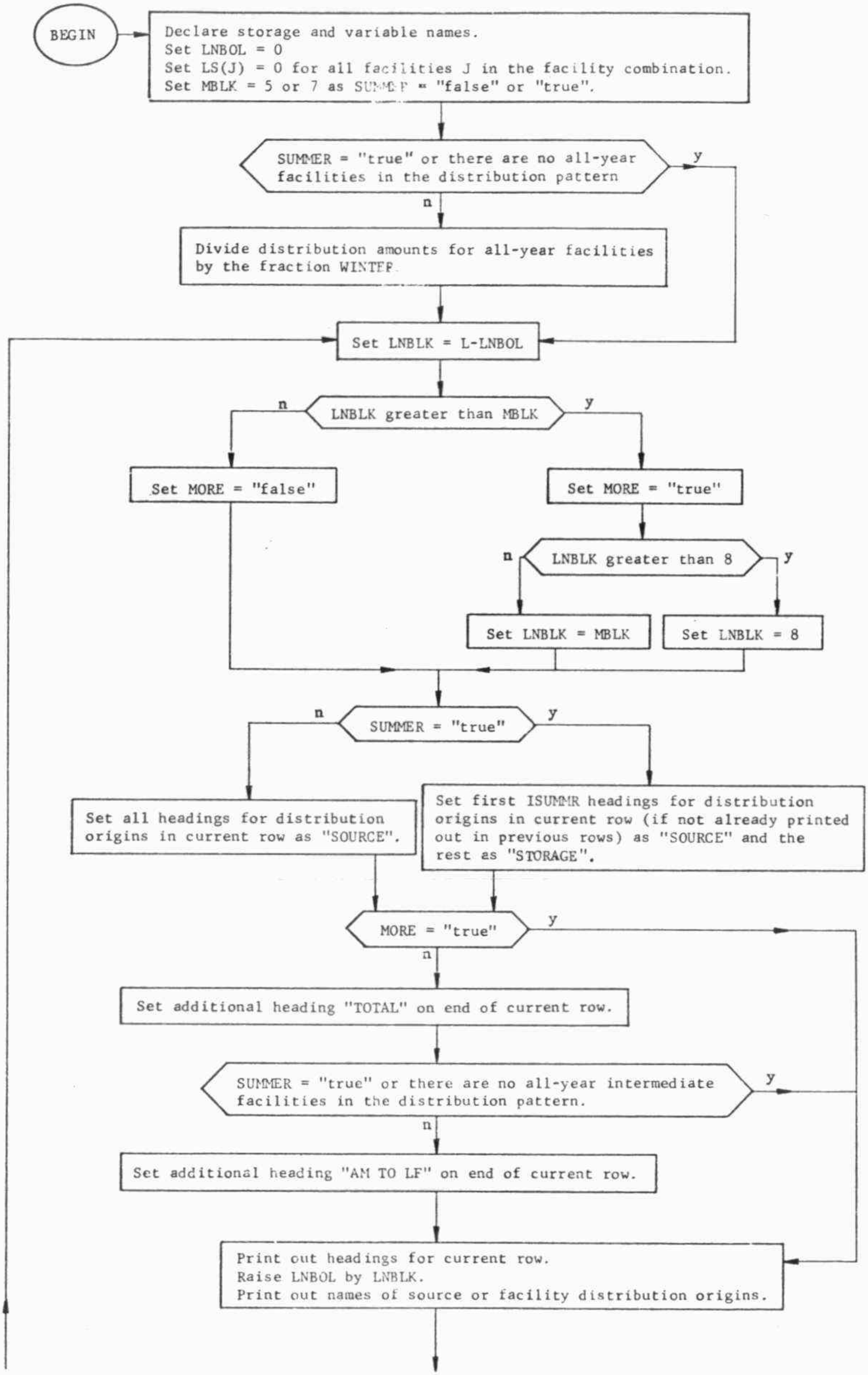
Using the labels G and R, trace the path to row J back to its beginning (indicated by G(I) = INF), and superimpose upon it the maximum flow possible, thus increasing X on links in a forward direction and decreasing X on links in a backward direction. Update A,B,GD and the List LS of zero dual constraints with X greater than zero.

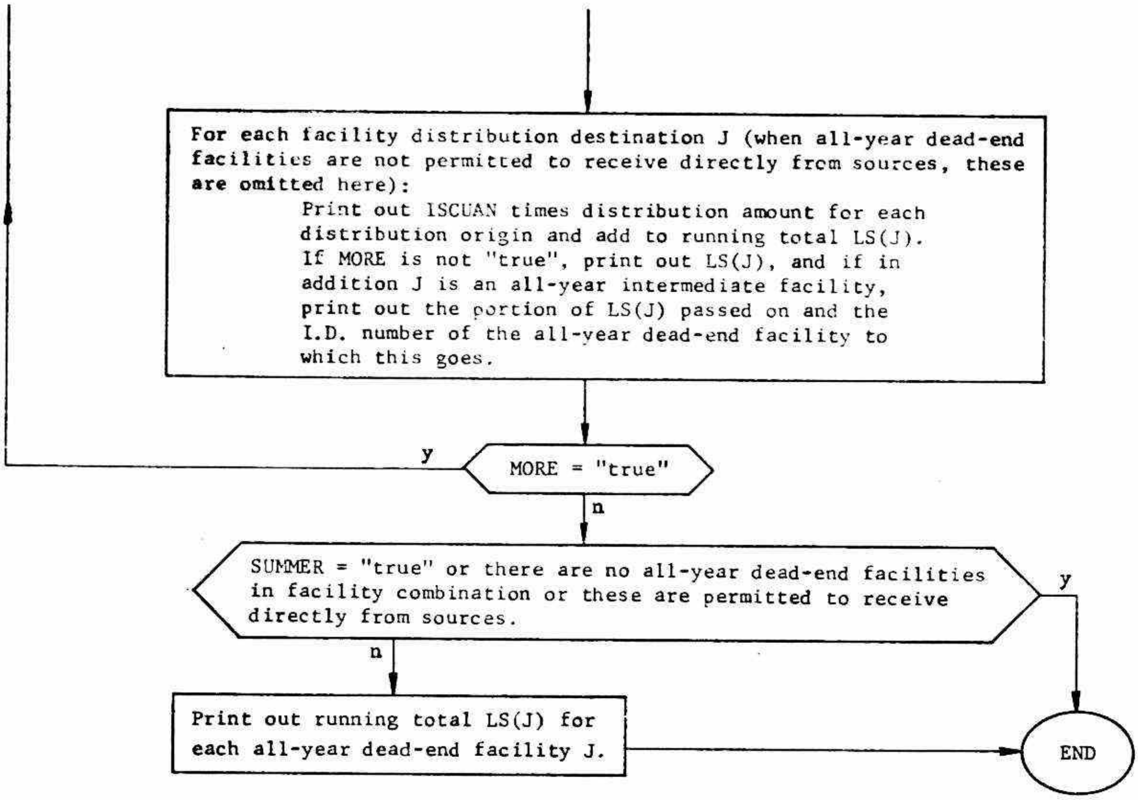
In each labelled row (stored in LISTV), look for a zero dual constraint with X(I,J) greater than zero (stored in LS) at the intersection of an unlabelled column (indicated by G(I) = 0). As each is found, record the column I in LISTU and label the column by setting G(I) = J.

Find the smallest dual constraint C(I,J)over all the intersections of labelled columns and labelled rows and set H equal to this value. Simultaneously, list unlabelled rows in the beginning of LISTV, and list labelled rows in the end of LISTV.

```
For each column I:
    Reset NLV(I) = N*(I - 1); that is, there are no zero dual constraints
    with J's listed in NL at this point.
    For each labelled row J (listed in end of LISTV):
        Add H to C(I,J) if I is unlabelled (indicated by G(I) = 0).
        If C(I,J) is now zero, list J in NL and update NLV(I)
        accordingly.
    For each unlabelled row J (listed in beginning of LISTV):
        Subtract H from C(I,J) if I is labelled (indicated by
        G(I) greater than zero).
        If C(I,J) is now zero, list J in NL and update NLV(I)
        accordingly.
```

FIGURE 57. SUBROUTINE LAYOUT FLOWCHART


BEGIN
Declare storage and variable names.
Set LNBOL = 0
Set LS(J) = 0 for all facilities J in the facility combination.
Set MBLK = 5 or 7 as SUMMER = "false" or "true".
SUMMER = "true" or there are no all-year facilities in the distribution pattern
y
n
Divide distribution amounts for all-year facilities by the fraction WINTER.
Set LNBLK = L-LNBOL
n
LNBLK greater than MBLK
y
Set MORE = "false"
Set MORE = "true"
n
LNBLK greater than 8
y
Set LNBLK = MBLK
Set LNBLK = 8
n
SUMMER = "true"
y
Set all headings for distribution origins in current row as "SOURCE".
Set first ISUMMR headings for distribution origins in current row (if not already printed out in previous rows) as "SOURCE" and the rest as "STORAGE".
MORE = "true"
y
n
Set additional heading "TOTAL" on end of current row.
SUMMER = "true" or there are no all-year intermediate facilities in the distribution pattern.
y
n
Set additional heading "AM TO LF" on end of current row.
Print out headings for current row.
Raise LNBOL by LNBLK.
Print out names of source or facility distribution origins.


For each facility distribution destination J (when all-year dead-end facilities are not permitted to receive directly from sources, these are omitted here):
Print out ISCUAN times distribution amount for each distribution origin and add to running total LS(J).
If MORE is not "true", print out LS(J), and if in addition J is an all-year intermediate facility, print out the portion of LS(J) passed on and the I.D. number of the all-year dead-end facility to which this goes.
y
MORE = "true"
n
SUMMER = "true" or there are no all-year dead-end facilities in facility combination or these are permitted to receive directly from sources.
y
n
Print out running total LS(J) for each all-year dead-end facility J.
END

NOTE: LNBLK is the number of source or facility distribution origins to be printed out in current row.
L is the total number of such origins in the distribution pattern (excluding all-year dead-end facilities when these are not permitted to receive directly from sources).

APPENDIX VI

ALL02 LISTING

APPENDIX VI

ALL02 LISTING

Following is the complete listing of the ALL02 source program as used for the preparation of this manual. It compiles into 1000 lines of object code as produced by IBM's Fortran G compiler.

```
C      MAIN PROGRAM ALL02                                               00005000
      COMMON/STARTB/ALPHA,TITLE(20),W(80),MFC1(4),OAMF(30),KF(30),JCOF(200010000
     *0),HAULF(9),HAULV(9)                                              00020000
      COMMON/LINDAT/NL(320),INTG(16),LISTU(16),NLV(16),LS(320),INTR(20),00030000
     *LISTV(20),LSV(20),A(16),B(20),C(16,20),X(16,20),KVC(16,20),CRIT,KW00040000
     *,M,N,ZWAT                                                         00050000
      COMMON/LAYDAT/ISUMMR,SUMMER,MPP0,ML00,MLF0,MLF1,MLFN,MPPN,MHT,NFAC00060000
     *,IR1,IW1,IR2,IW2,ILP1(30),ILP2(30),JLP(30),LFPP(30),JOUT(30),IH(6)00070000
      DIMENSIONNOTUSE(30),U(20),UMINP(30),KMINP(30)                     00080000
      COMMON/INLARB/NSTOR,NOSMMR,LINCAL,NS2,NS3,NS4,NHT2,NHT3,NHT4,NPP2,00090000
     *NPP3,NPP4,INF,NSETS,EPS,IEPS,IDEFIN,NEXSET,ARBOUT,FACSET,NEXPON,NF00100000
     *RTAB,NSOL,MAXSOL,CURMIN,CURMAX,OLDMAX,CMINPS,SUMQ,IWINT,IWINT2,IS00110000
     *MM,IWFAC,ISCUAN,IDUMP,CONF(30),CAP(30),CTRANS(10,30),CTRANL(10,20)00120000
     *,CTRANP(10,20),Q(10),IDSOL(20),ZSOL(20),MTWO(30),BAR(30),OLDBAR(3000130000
     *),KTRANS(10,30),KTRANP(10,20)                                     00140000
      COMMON/INSMAB/KASCNT,NF,NS,NLS,NPP,NLF,NHT,NLS1,NLSN,NPP1,NPPN,NLF00150000
     *1,NLFN,NHT1,NHTN,SIZE,MSIZ,NFN,LTAB,RTAB,ITAB,OTAB,NTAB,TTYP,LMAX,00160000
     *MAXSIZ(4),NAVA(30),OLNAVA(30),IYP(30),MFC(4)                      00170000
      COMMON/ACONVB/NAMSRC(10),NAMFAC(30)                               00180000
      COMMON/REALB/SCALE,DISTNS(10,30),DISTNL(10,20),DISTNP(10,20),VRED(00190000
     *30)                                                               00200000
      COMMON/LOGICB/LCTNL0,LCTNP0,NLS0,NPP0,NLF0,NHT0,IDEF0,STOSET,SAFSE00210000
     *T,HTINC,LFINC,LSINC,PPINC,LSHTIN,PPLFIN,L00,L01,                 L0000220000
     *PPN,LSCHT0,PCFOL1,HTSUPF,LFSUPF,HTESSN,LFESSN,SIZE1,NFNSIZ,SIZMTY,00230000
     *SNINC,MORE,NYOUT,NOBLOC(900),INC(30),COND(4),MSET(30),SUPF(30)    00240000
      INTEGEREPS,ARBOUT,FACSET,CURMIN,CURMAX,OLDMAX,CMINPS,SUMQ,CONF,CAP00250000
     *,CTRANS,CTRANL,CTRANP,Q,ZSOL,SIZE,RTAB,OTAB,BAR,OLDBAR,OLNAVA,INSM00260000
     *AS(123),INLARS(1435),ACONVS(40),TITLE,UAMF,CRIT,U,UMINP,A,B,C,X,Z,00270000
     *ZF,UMINI,UCIM,QJ,T,P                                              00280000
      REALREALS(731)                                                    00290000
      LOGICALLCTNL0,LCTNP0,NLS0,NPP0,NLF0,NHT0,IDEF0,STOSET,SAFSET,HTINC00300000
     *,LFINC,LSINC,PPINC,LSHTIN,PPLFIN,L00,L01,                 L00PPN,LSC00310000
     *HT0,PCFOL1,HTSUPF,LFSUPF,HTESSN,LFESSN,SIZE1,NFNSIZ,SIZMTY,SNINC,M00320000
     *ORE,NYOUT,NOBLOC,INC,COND,MSET,SUPF                               00330000
      LOGICALLOGICS(1024),ZWAT,MLS0,MPP0,MLF0,MHT0,MLOH0,SUMMER,NOTUSE,W00340000
     *VIOL,SVIOL,SURVEY,NETOUT,MLSC,MPPC,MLFC,MHTC,MLSEQ1,MPSLF1,ML00   00350000
      EQUIVALENCE(LCTNL0,LOGICS(1)),(NSTOR,INLARS(1)),(KASCNT,INSMAS(1))00360000
     *,(SCALE,REALS(1)),(ACONVS(1),NAMSRC(1))                           00370000
      DATAIEND/4H====/,IHREST/4HREST/                                   00380000
      KFIX(R)=IFIX(0.5+R)                                               00390000
      ISC(I)=KFIX(FLOAT(I)/SCALE)                                       00400000
      CRIT=INF                                                          00410000
      READ(IR1,503)TITLE                                                00420000
      WRITE(IW1,600)TITLE                                               00430000
C DETERMINE IF CONTINUATION OF PREVIOUS RUN                             00440000
      IF(TITLE(1).NE.IHREST)GOTO0007                                    00450000
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX00460000
      READ(IR2,800)LOGICS                                               00470000
      READ(IR2,801)INSMAS                                               00480000
      READ(IR2,802)INLARS                                               00490000
      READ(IR2,804)ACONVS                                               00500000
      READ(IR2,805)REALS                                                00510000
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX00520000
      GOTO1601                                                          00530000
0007  KASCNT=0                                                          00540000
0008  CALLSTART                                                         00550000
      IF(IDEF0)GOTO1613                                                 00560000
      GOTO1602                                                          00570000
C**********************  C O S T   S U R V E Y  ********************    00580000
 0160 IF(NETOUT)NEXSET=NEXSET+ARBOUT                                    00590000
```

```
      IF(FACSET.LT.NEXPUN)GOTO1601                                      00600000
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX00610000
      WRITE(IW2,803)                                                    00620000
      WRITE(IW2,800)LOGICS                                              00630000
      WRITE(IW2,801)INSMAS                                              00640000
      WRITE(IW2,802)INLARS                                              00650000
      WRITE(IW2,804)ACONVS                                              00660000
      WRITE(IW2,806)REALS                                               00670000
      WRITE(IW2,807)FACSET                                              00675000
      WRITE(IW1,807)FACSET                                              00680000
      NEXPUN=NEXPUN+IDUMP                                               00690000
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX00700000
 1601 IF(IDEF0)GOTO1620                                                 00710000
      IF(FACSET.EQ.IDEFIN)GOTO1000                                      00720000
 1602 READ(IR1,509)NFAC,(JOUT(J),J=1,NFAC)                              00730000
      WRITE(IW1,625)(JOUT(J),J=1,NFAC)                                  00740000
      GOTO168                                                           00750000
C INITIAL SUBSET GENERATING ROUTINE                                     00760000
 1613 IF(LSHTIN.OR.PPLFIN.OR.(LFINC.AND.L01))GOTO1616                   00770000
      SIZMTY=.FALSE.                                                    00780000
 1614 SNINC=.FALSE.                                                     00790000
C SUBSET SIZE RAISING ROUTINE                                           00800000
 1617 IF(SIZMTY)GOTO1000                                                00810000
      MSIZ=SIZE                                                         00820000
      MORE=MSIZ.GT.0                                                    00830000
      SIZE1=MORE                                                        00840000
      SIZE=SIZE+1                                                       00850000
      NFNSIZ=SIZE.EQ.NFN                                                00860000
      DO1618I=1,NF                                                      00870000
      BAR(I)=OLDBAR(I)                                                  00880000
      MSET(I)=.FALSE.                                                   00890000
      NAVA(I)=OLNAVA(I)                                                 00900000
 1618 SUPF(I)=.FALSE.                                                   00910000
      MFC(1)=0                                                          00920000
      MFC(2)=0                                                          00930000
      MFC(3)=0                                                          00940000
      MFC(4)=0                                                          00950000
      NTAB=LTAB                                                         00960000
      ITAB=RTAB                                                         00970000
      OTAB=0                                                            00980000
      HTSUPF=.FALSE.                                                    00990000
      LFSUPF=.FALSE.                                                    01000000
      SIZMTY=.TRUE.                                                     01010000
      GOTO1624                                                          01020000
 1616 SNINC=.TRUE.                                                      01030000
      GOTO1654                                                          01040000
C NEW SUBSET GENERATING ROUTINE                                         01050000
 1620 IF(SNINC)GOTO1614                                                 01060000
      IF(NFNSIZ)GOTO1000                                                01070000
      MSET(NTAB)=.FALSE.                                                01080000
      MFC(ITYP)=MFC(ITYP)-1                                             01090000
      IF(NTAB.GE.ITAB)GOTO1642                                          01100000
 1621 NTAB=NTAB+1                                                       01110000
      IF(NTAB.GT.RTAB.OR.NAVA(NTAB).LT.MSIZ)GOTO1640                    01120000
      IF(SUPF(NTAB))GOTO1621                                            01130000
      IF(BAR(NTAB).EQ.0)GOTO1624                                        01140000
 1622 IF(LFESSN.AND.NTAB.EQ.NLFN)GOTO1640                               01150000
 1623 IF(NAVA(NTAB).EQ.MSIZ)GOTO1640                                    01160000
      GOTO1621                                                          01170000
 1624 ITYP=IYP(NTAB)                                                    01180000
```

```
      IF(SIZE1)GOTO1625
      IF((ITYP.EQ.1.AND..NOT.HTINC).OR.(ITYP.EQ.2.AND..NOT.LFINC).OR.(IT
     *YP.EQ.3.AND.LOOPPN).OR.(ITYP.EQ.4.AND..NOT.LSINC))GOTO1623
      GOTO1626
1625  IF(MFC(ITYP).EQ.MAXSIZ(ITYP))GOTO1622
      IF(LFINC.OR..NOT.HTESSN.OR.MSIZ.NE.1.OR.ITYP.NE.2)GOTO1626
      NTAB=NPPN
      GOTO1623
1626  MFC(ITYP)=MFC(ITYP)+1
      IF(LSCHTO.OR.HTSUPF.OR.MFC(1).GT.0.OR.NTAB.LT.NLSN)GOTO1632
      DO16315K=NHT1,NHTN
16315 SUPF(K)=.TRUE.
      HTSUPF=.TRUE.
      IF(.NOT.SUPF(NTAB))GOTO1632
      MFC(ITYP)=MFC(ITYP)-1
      GOTO1640
1632  IF(PCFOL1.OR.LFSUPF.OR.MFC(2).GT.0.OR.NTAB.LT.NPPN)GOTO16265
      DO16325K=NLF1,NLFN
16325 SUPF(K)=.TRUE.
      LFSUPF=.TRUE.
      IF(.NOT.SUPF(NTAB))GOTO16265
      MFC(ITYP)=MFC(ITYP)-1
      NTAB=NLFN
      GOTO1623
16265 MSET(NTAB)=.TRUE.
      IF(NTAB.LT.ITAB)GOTO1628
      ITAB=NTAB
      IF(ITAB.EQ.1)GOTO1628
1627  ITAB=ITAB-1
      IF(ITAB.EQ.1)GOTO1628
      IF(MSET(ITAB).OR.SUPF(ITAB).OR.INC(ITAB))GOTO1627
1628  IF(.NOT.MORE)GOTO1654
C BUILDING ROUTINE
 1629 J=NF*NTAB
      I=NF
      L=0
      DO1631K=1,NF
      IF(NOBLOC(J))GOTO1630
      IF(BAR(I).EQ.0)L=L+1
      BAR(I)=BAR(I)+1
1630  I=I-1
      IF(L.GT.0.AND.I.GT.0)NAVA(I)=NAVA(I)-L
1631  J=J-1
      OTAB=NTAB
      MSIZ=MSIZ-1
      IF(NAVA(NTAB).LE.MSIZ)GOTO1640
      MORE=MSIZ.GT.0
1633  LFESSN=.FALSE.
      IF(HTINC.OR.MFC(1).EQ.0.OR.MFC(4).GT.0)GOTO1635
      HTESSN=.TRUE.
      IF(LFINC.OR.MFC(2).EQ.0.OR.MFC(3).GT.0)GOTO1634
      LFESSN=.TRUE.
      IF(MSIZ.EQ.1)NTAB=NPPN
      GOTO1621
 1634 IF(.NOT.MORE)NTAB=NLFN
      GOTO1621
1635  HTESSN=.FALSE.
      IF(LFINC.OR.MFC(2).EQ.0.OR.MFC(3).GT.0)GOTO1621
      LFESSN=.TRUE.
      IF(MSIZ.EQ.0)NTAB=NPPN
      GOTO1621
C BACKTRACKING ROUTINE
 1640 IF(NFNSIZ)GOTO1000
1642  IF(OTAB.LT.LTAB)GOTO1617
      NTAB=OTAB
      IF(ITAB.LT.OTAB)NTAB=ITAB
1643  IF(MSET(NTAB))GOTO1644
      IF(NTAB.EQ.LTAB)GOTO1617
      NTAB=NTAB-1
      GOTO1643
1644  J=NFRTAB
      N=RTAB
      DO1648M=NTAB,RTAB
      IF(.NOT.MSET(N))GOTO1647
      MSET(N)=.FALSE.
      MSIZ=MSIZ+1
      I=IYP(N)
      MFC(I)=MFC(I)-1
      L=0
      I=NF
      DO1646K=1,NF
      IF(NOBLOC(J))GOTO1645
      BAR(I)=BAR(I)-1
      IF(BAR(I).EQ.0)L=L+1
1645  I=I-1
      IF(L.GT.0.AND.I.GT.0)NAVA(I)=NAVA(I)+L
1646  J=J-1
      GOTO1648
1647  J=J-NF
1648  N=N-1
      OTAB=NTAB-1
      IF(NAVA(NTAB).LE.MSIZ)GOTO1642
      ITAB=RTAB
      MORE=MSIZ.GT.0
      IF(.NOT.HTSUPF)GOTO1649
      IF(MFC(1).GT.0.OR.NTAB.LT.NLSN)GOTO1650
1649  IF(.NOT.LFSUPF)GOTO1633
      IF(MFC(2).GT.0.OR.NTAB.LT.NPPN)GOTO1651
1650  HTSUPF=.FALSE.
      DO16505K=NHT1,NHTN
16505 SUPF(K)=.FALSE.
      GOTO1649
 1651 LFSUPF=.FALSE.
      DO16515K=NLF1,NLFN
16515 SUPF(K)=.FALSE.
      GOTO1633
C JOUT TRANSLATION ROUTINE
 1654 SIZMTY=.FALSE.
      IF(LSHTIN)GOTO1655
      COND(1)=MFC(4).GT.0
      COND(4)=MFC(1).GT.0
1655  IF(PPLFIN)GOTO1656
      COND(2)=MFC(3).GT.0
      COND(3)=L01.OR.MFC(2).GT.0
1656  NFAC=0
      MFC1(1)=0
      MFC1(2)=0
      MFC1(3)=0
      MFC1(4)=0
      DO1660I=1,NF
      K=IYP(I)
      IF(MSET(I).OR.(INC(I).AND.COND(K)))GOTO1658
      GOTO1660
1658  NFAC=NFAC+1
      JOUT(NFAC)=I
      MFC1(K)=MFC1(K)+1
1660  CONTINUE
      MLS=MFC1(1)
      MPP=MFC1(2)
      MLF=MFC1(3)
      MHT=MFC1(4)
C ************* END OF COMBEX ROUTINE ***********
      GOTO1735
C                                ------ SUBSET TAB ROUTINE -------
 168  MLS=0
      MPP=0
      MLF=0
      MHT=0
      J=1
169   IF(JOUT(J).GT.NLSN)GOTO171
      MLS=MLS+1
      IF(J.EQ.NFAC)GOTO173
      J=J+1
      GOTO169
171   IF(JOUT(J).GT.NPPN)GOTO172
      MPP=MPP+1
      IF(J.EQ.NFAC)GOTO173
      J=J+1
      GOTO171
172   IF(JOUT(J).GT.NLFN)GOTO173
      MLF=MLF+1
      IF(J.EQ.NFAC)GOTO173
      J=J+1
      GOTO172
0173  MHT=NFAC-(MLS+MPP+MLF)
1735  MLS0=MLS.EQ.0
      MLF0=MLF.EQ.0
      MPP0=MPP.EQ.0
      MHT0=MHT.EQ.0
      MLS1=1
      IF(MLS0)MLS1=0
      MLSN=MLS
      MPP1=MLSN
      IF(.NOT.MPP0)MPP1=MLSN+1
      MPPN=MLSN+MPP
      MLF1=MPPN
      IF(.NOT.MLF0)MLF1=MPPN+1
      MLFN=MPPN+MLF
      MHT1=MLFN
      IF(.NOT.MHT0)MHT1=MLFN+1
      MHTN=NFAC
C                                ---------------------------------
      IF(STOSET)GOTO174
      FACSET=FACSET+1
      NETOUT=FACSET.EQ.NEXSET
      SURVEY=.NOT.NETOUT
      IF(SURVEY)GOTO279
      WRITE(IW1,626)FACSET
0174  DO175I=1,NFAC
 0175 NL(I)=NAMFAC(JOUT(I))
```

```
      IF(MLSO)GOTO275
      WRITE(IW1,7601)(JOUT(J),NL(J),J=1,MLS)
275   IF(MPPO)GOTO277
      WRITE(IW1,7602)(JOUT(J),NL(J),J=MPP1,MPPN)
277   IF(MLFO)GOTO278
      WRITE(IW1,7604)(JOUT(J),NL(J),J=MLF1,MLFN)
278   IF(MHTO)GOTO279
      WRITE(IW1,7605)(JOUT(J),NL(J),J=MHT1,MHTN)
279   ZF=0
      DO280J=1,NFAC
280   ZF=ZF+CONF(JOUT(J))
      IF(NETOUT)GOTO281
      CRIT=CMINPS-ZF
      IF(CRIT.LE.0)GOTO160
0281  IF(SAFSET)GOTO313
C.....FIND WHICH OF GIVEN FACILITIES MAY BE USEFUL
      MPPC=MPPO
      IF(MLFO)MPPC=.TRUE.
      MLFC=MLFO
      IF(MPPO.AND.LOO)MLFC=.TRUE.
      MLSC=MLSO
      IF(MHTO)MLSC=.TRUE.
      MHTC=MHTO
      IF(MLSO)MHTC=.TRUE.
      IF(.NOT.(MLSC.AND.MPPC.AND.MLFC.AND.MHTC))GOTO294
      IF(NETOUT)WRITE(IW1,7707)
      GOTO160
C.....ELIMINATE USELESS FACILITIES FROM JOUT
 294  M=0
      N=0
      L=NFAC
      IF(MHTC.AND.MHTO.OR..NOT.MHTC.AND..NOT.MHTO)GOTO303
      NFAC=NFAC-MHT
      MHT=0
      MHTO=.TRUE.
      MHT1=MHT1-1
303   IF(MLFC.AND.MLFO.OR..NOT.MLFC.AND..NOT.MLFO)GOTO306
      IF(MLFN.EQ.NFAC)GOTO305
      K=MLFN+1
      DO304J=K,NFAC
304   JOUT(J-MLF)=JOUT(J)
305   NFAC=NFAC-MLF
      MHT1=MHT1-MLF
      MLF=0
      MLFO=.TRUE.
      MLF1=MLF1-1
      MLFN=MLF1
306   IF(MPPC.AND.MPPO.OR..NOT.MPPC.AND..NOT.MPPO)GOTO309
      IF(MPPN.EQ.NFAC)GOTO308
      K=MPPN+1
      DO307J=K,NFAC
307   JOUT(J-MPP)=JOUT(J)
308   NFAC=NFAC-MPP
      MHT1=MHT1-MPP
      M=MPP
      MPP=0
      MPPO=.TRUE.
      MPP1=MPP1-1
      MPPN=MPP1
309   IF(MLSC.AND.MLSO.OR..NOT.MLSC.AND..NOT.MLSO)GOTO312
```

```
      IF(MLSN.EQ.NFAC)GOTO311
      K=MLSN+1
      DO310J=K,NFAC
310   JOUT(J-MLS)=JOUT(J)
311   NFAC=NFAC-MLS
      MHT1=MHT1-MLS
      M=M+MLS
      N=MLS
      MLS=0
      MLS0=.TRUE.
      MLS1=0
      MLSN=0
0312  IF(NFAC.EQ.L)GOTO313
      MHTN=NFAC
      MLFN=MLFN-M
      MLF1=MLF1-M
      MPPN=MPPN-N
      MPP1=MPP1-N
313   MLQ0=MLF0.OR.L00
      MLQH0=MLQ0.AND.MH10
      MLSEQ1=MLS.EQ.1
      I=MPF+MHT
      IF(L01)I=I+MLF
      MPSLF1=I.EQ.1
C.....FIND EXCESS CAPACITY
      K=MLSN+1
      SUMCAP=0
      DO314J=K,NFAC
314   SUMCAP=SUMCAP+CAP(JOUT(J))
      IF(SUMQ.LE.SUMCAP)GOTO315
      IF(NETOUT)WRITE(IW1,7708)
      GOTO160
0315  IF(SURVEY)GOTO178
      I=ISC(ZF)
      WRITE(IW1,7608)I
C.....ASSIGN CHEAPEST LF FOR EACH PP
 0178 IF(MPP0.OR.MLF0)GOTO162
      DO181I=MPP1,MPPN
      I2=JOUT(I)
      I1=I2-NLSN
      UMINI=INF
      DO180J=MLF1,MLFN
      J1=JOUT(J)-NPPN
      IF(KTRANP(I1,J1).GE.UMINI)GOTO180
      UMINI=KTRANP(I1,J1)
      JBEST=J
0180  CONTINUE
      LFPP(I)=JBEST
      J=JOUT(JBEST)
      IF(NETOUT)WRITE(IW1,7607)I2,NAMFAC(I2),J,NAMFAC(J)
      KMINP(I)=KFIX(FLOAT(CTRANP(I1,J))*VRED(I2))
 181  UMINP(I)=KFIX(FLOAT(UMINI)*VRED(I2))
0182  IF(NETOUT)GOTO198
      DO1810I=1,NFAC
1810  NOTUSE(I)=.TRUE.
C.....ASSIGN CHEAPEST DESTINATIONS TO SOURCES FOR WINTER SYSTEM
      DO183J=1,NFAC
183   KF(J)=0
      DO184I=1,NS
184   A(I)=0
```

```
      Z=0                                                               04190000
      WVIOL=.FALSE.                                                     04200000
      ISUMMR=0                                                          04210000
      DO187I=1,NS                                                       04220000
      UMINI=INF                                                         04230000
      IF(MPP0)GOTO1851                                                  04240000
      DO185J=MPP1,MPPN                                                  04250000
      UCTM=KTRANS(I,JOUT(J))+UMINP(J)                                   04260000
      IF(UCTM.GE.UMINI)GOTO185                                          04270000
      JBEST=J                                                           04280000
      UMINI=UCTM                                                        04290000
0185  CONTINUE                                                          04300000
      KMINI=CTRANS(I,JOUT(JBEST))+KMINP(JBEST)                          04310000
 1851 IF(MLOH0)GOTO1861                                                 04320000
      L=MLF1                                                            04330000
      IF(MLQ0)L=MHT1                                                    04340000
      DO186J=L,NFAC                                                     04350000
      J1=JOUT(J)                                                        04360000
      UCTM=KTRANS(I,J1)                                                 04370000
      IF(UCTM.GE.UMINI)GOTO186                                          04380000
      JBEST=J                                                           04390000
      UMINI=UCTM                                                        04400000
      KMINI=CTRANS(I,J1)                                                04410000
0186  CONTINUE                                                          04420000
1861  Z=Z+Q(I)*KMINI                                                    04430000
      IF(Z.GE.CRIT)GOTO160                                              04440000
      IF(WVIOL)GOTO1862                                                 04450000
      QJ=KF(JBEST)+Q(I)                                                 04460000
      IF(QJ.LE.CAP(JOUT(JBEST)))GOTO18615                               04470000
      IF(MPSLF1)GOTO160                                                 04480000
      WVIOL=.TRUE.                                                      04490000
18615 KF(JBEST)=QJ                                                      04500000
      NOTUSE(JBEST)=.FALSE.                                             04510000
      IF(JBEST.LE.MPPN)NOTUSE(LFPP(JBEST))=.FALSE.                      04520000
C.........IF JBEST IS NOT AN HT SKIP THE ADDITION TO SUMMER SOURCES     04530000
 1862 IF(JBEST.LE.MLFN)GOTO187                                          04540000
      ISUMMR=1                                                          04550000
      A(I)=(Q(I)*ISUMM+IWINT2)/IWINT                                    04560000
 187  CONTINUE                                                          04570000
      KW=Z                                                              04580000
C.....ASSIGN CHEAPEST LS FOR EACH HT AND SOURCE ACTIVE IN SUMMER SYSTEM 04590000
      SVIOL=.FALSE.                                                     04600000
      IF(ISUMMR.EQ.0)GOTO194                                            04610000
      DO189I=MHT1,NFAC                                                  04620000
      IF(KF(I).LE.0)GOTO189                                             04630000
      I1=JOUT(I)                                                        04640000
      KF(I)=KFIX(FLOAT(KF(I))*VRED(I1))                                 04650000
      I1=I1-NLFN                                                        04660000
      UMINI=INF                                                         04670000
      DO188J=1,MLS                                                      04680000
      UCTM=CTRANL(I1,JOUT(J))                                           04690000
      IF(UCTM.GE.UMINI)GOTO188                                          04700000
      JBEST=J                                                           04710000
      UMINI=UCTM                                                        04720000
188   CONTINUE                                                          04730000
      Z=Z+KF(I)*UMINI                                                   04740000
      IF(Z.GE.CRIT)GOTO160                                              04750000
      IF(WVIOL.OR.SVIOL)GOTO189                                         04760000
      QJ=KF(JBEST)+KF(I)                                                04770000
      IF(QJ.LE.CAP(JOUT(JBEST)))GOTO1885                                04780000
      IF(MLSEQ1.AND..NOT.WVIOL)GOTO160
      SVIOL=.TRUE.
1885  KF(JBEST)=QJ
      NOTUSE(JBEST)=.FALSE.
189   CONTINUE
      DO191I=1,NS
      IF(A(I).LE.0)GOTO191
      UMINI=INF
      DO190J=1,MLS
      UCTM=CTRANS(I,JOUT(J))
      IF(UCTM.GE.UMINI)GOTO190
      JBEST=J
      UMINI=UCTM
0190  CONTINUE
      Z=Z+A(I)*UMINI
      IF(Z.GE.CRIT)GOTO160
      IF(WVIOL.OR.SVIOL)GOTO191
      QJ=KF(JBEST)+A(I)
      IF(QJ.LE.CAP(JOUT(JBEST)))GOTO1905
      IF(MLSEQ1.AND..NOT.WVIOL)GOTO160
      SVIOL=.TRUE.
1905  KF(JBEST)=QJ
      NOTUSE(JBEST)=.FALSE.
0191  CONTINUE
0194  IF(WVIOL)GOTO198
      IF(SVIOL.AND..NOT.MLS0)GOTO1948
      Z=Z+ZF
      GOTO900
C.....UNCONSTRAINED OPTIMIZATION GAVE Z.LT.CMINPS AND EXCEEDED ONLY THE
C.....SUMMER LIMITATIONS...DO SPECIAL SETUP FOR LINPRO ON SUMMER SYSTEM
 1948 DO1949I=1,MLS
1949  NOTUSE(I)=.TRUE.
      I1=0
      T=0
      DO195I=1,NS
      QJ=A(I)
      IF(QJ.LE.0)GOTO195
      I1=I1+1
      A(I1)=QJ
      T=T+QJ
      DO1951J=1,MLS
      J1=CTRANS(I,JOUT(J))
      KWC(I1,J)=J1
1951  C(I1,J)=J1
 0195 CONTINUE
      DO196I=MHT1,MHTN
      QJ=KF(I)
      IF(QJ.LE.0)GOTO196
      I1=I1+1
      A(I1)=QJ
      T=T+QJ
      J1=JOUT(I)-NLFN
      DO1961J=1,MLS
      J2=CTRANL(J1,JOUT(J))
      KWC(I1,J)=J2
1961  C(I1,J)=J2
 0196 CONTINUE
      Z=KW+ZF
      GOTO212
C.....UNCONSTRAINED OPTIMIZATION GAVE Z.LT.CMINPS BUT EXCEEDED WINTER
```

```
C.....LIMITATIONS...DO SETUP FOR LINPRO ON WINTER SYSTEM
 198  DO200I=1,NS
      ILP1(I)=I
      ILP2(I)=NAMSRC(I)
200   A(I)=Q(I)
      DO2001I=1,NFAC
2001  NOTUSE(I)=.TRUE.
      M=NS+1
      A(M)=SUMCAP-SUMQ
      J1=0
      IF(MPP0)GOTO202
      DO201J=MPP1,MPPN
      J1=J1+1
      J2=JOUT(J)
      JLP(J1)=J
      B(J1)=CAP(J2)
      UMINI=UMINP(J)
      KMINI=KMINP(J)
      KWC(M,J1)=0
      C(M,J1)=0
      DO201I=1,NS
      KWC(I,J1)=CTRANS(I,J2)+KMINI
0201  C(I,J1)=KTRANS(I,J2)+UMINI
 202  IF(MLQH0)GOTO204
      K=MLF1
      IF(MLQ0)K=MHT1
      DO203J=K,NFAC
      J1=J1+1
      J2=JOUT(J)
      JLP(J1)=J
      B(J1)=CAP(J2)
      KWC(M,J1)=0
      C(M,J1)=0
      DO203I=1,NS
      KWC(I,J1)=CTRANS(I,J2)
0203  C(I,J1)=KTRANS(I,J2)
 204  N=J1
      IF(SURVEY.OR.N.NE.1)GOTO2042
      KW=0
      DO2041I=1,M
      X(I,1)=A(I)
 2041 KW=KW+X(I,1)*KWC(I,1)
      B(1)=0
      GOTO2043
2042  CALLLINPRO
      KW=0
      DO206J=1,N
      ZWAT=.TRUE.
      DO205I=1,NS
      IF(X(I,J).LE.0)GOTO205
      KW=KW+KWC(I,J)*X(I,J)
      IF(SURVEY.AND.KW.GT.CRIT)GOTO0160
      ZWAT=.FALSE.
0205  CONTINUE
      IF(ZWAT)GOTO206
      K=JLP(J)
      NOTUSE(K)=.FALSE.
      IF(K.LE.MPPN)NOTUSE(LFPP(K))=.FALSE.
0206  CONTINUE
2043  Z=ZF+KW
```

```
      IF(SURVEY)GOTO2044
      SUMMER=.FALSE.
      CALLLAYOUT
      I=ISC(KW)
      J=ISC(Z)
      WRITE(IW1,7610)I,J
 2044 IF(.NOT.MHTO)GOTO207
      IF(NETOUT)WRITE(IW1,7611)
      IF(STOSET)GOTO1100
      GOTO900
C.....SETUP NOW FOR SUMMER SYSTEM
 207  I1=0
      K=N-MHT+1
      T=0
      DO210I=1,NS
      QJ=0
      DO209J=K,N
209   QJ=QJ+X(I,J)
      IF(QJ.LE.0)GOTO210
      I1=I1+1
      ILP1(I1)=I
      ILP2(I1)=NAMSRC(I)
      QJ=(QJ*ISUMM+IWINT2)/IWINT
      A(I1)=QJ
      T=T+QJ
      DO2101J=1,MLS
      J1=CTRANS(I,JOUT(J))
      KWC(I1,J)=J1
2101  C(I1,J)=J1
 0210 CONTINUE
      IF(I1.NE.0)GOTO2102
      IF(NETOUT)WRITE(IW1,7611)
      IF(STOSET)GOTO1100
      GOTO900
2102  ISUMMR=I1
      DO211I=K,N
      J1=JOUT(JLP(I))
      QJ=KFIX(FLOAT(CAP(J1)-X(M,I))*VRED(J1))
      IF(QJ.EQ.0)GOTO211
      I1=I1+1
      ILP1(I1)=J1
      ILP2(I1)=NAMFAC(J1)
      A(I1)=QJ
      T=T+QJ
      J2=J1-NLFN
      DO2111J=1,MLS
      J1=CTRANL(J2,JOUT(J))
      KWC(I1,J)=J1
2111  C(I1,J)=J1
 0211 CONTINUE
0212  P=0
      M=I1+1
      DO213J=1,MLS
      JLP(J)=J
      QJ=CAP(JOUT(J))
      C(M,J)=0
      B(J)=QJ
      KWC(M,J)=0
 213  P=P+QJ
      IF(T.LE.P)GOTO2131
      NOSMMR=NOSMMR+1
      IF(NETOUT)WRITE(IW1,7709)
      IF(SURVEY)WRITE(IW1,712)(JOUT(J),J=1,NFAC)
      GOTO160
2131  A(M)=P-T
      IF(SURVEY)CRIT=CRIT-KW
      N=MLS
      IF(N.NE.1)GOTO2133
      KW=0
      DO2132I=1,M
      X(I,1)=A(I)
2132  KW=KW+X(I,1)*C(I,1)
      B(1)=0
      GOTO2134
2133  CALLLINPRO
      L=M-1
      KW=0
      DO215J=1,N
      ZWAT=.TRUE.
      DO2145I=1,L
      IF(X(I,J).LE.0)GOTO2145
      KW=KW+KWC(I,J)*X(I,J)
      IF(SURVEY.AND.KW.GT.CRIT)GOTO160
      ZWAT=.FALSE.
2145  CONTINUE
      NOTUSE(JLP(J))=ZWAT
215   CONTINUE
2134  Z=Z+KW
      IF(SURVEY)GOTO9001
      WRITE(IW1,7613)
      SUMMER=.TRUE.
      CALLLAYOUT
      I=ISC(KW)
      J=ISC(Z)
      WRITE(IW1,7615)I,J
      IF(STOSET)GOTO1100
0900  IF(SURVEY)GOTO9001
      IF(Z.GT.CMINPS)GOTO160
C***********************************************************************
C.....A SUBSET HAS BEEN FOUND TO GIVE Z.LT.CMINPS WITHIN ALL LIMITATIONS
C FIRST CHECK TO SEE IF SOLUTION IS ALREADY STORED
C CONSTRUCT CODE NUMBER FOR SUBSET
 9001 M=0
      K=1
      DO9003J=1,NF
      IF(JOUT(K).NE.J)GOTO9003
      IF(NOTUSE(K))GOTO9002
      M=M+MTWO(J)
9002  K=K+1
      IF(K.GT.NFAC)GOTO9004
9003  CONTINUE
 9004 IF(NSOL.EQ.0)GOTO9009
      DO9005I=1,NSOL
      IF(IDSOL(I).NE.M)GOTO9005
      IF(NETOUT)WRITE(IW1,7616)
      GOTO160
9005  CONTINUE
C                              --------- STORE ROUTINE -----------
 9009 NSTOR=NSTOR+1
      IF(Z.GE.CURMIN)GOTO901
      CURMIN=Z                                                          07190000
      CMINPS=Z+IEPS                                                     07200000
      IF(OLDMAX.GT.CMINPS)NYOUT=.FALSE.                                 07210000
901   IF(NSOL.EQ.MAXSOL)GOTO903                                         07220000
      NSOL=NSOL+1                                                       07230000
      ZSOL(NSOL)=Z                                                      07240000
      IDSOL(NSOL)=M                                                     07250000
      GOTO905                                                           07260000
903   IF(Z.GE.CURMAX)GOTO160                                            07270000
      OLDMAX=CURMAX                                                     07280000
      ZSOL(LMAX)=Z                                                      07290000
      IDSOL(LMAX)=M                                                     07300000
      IF(OLDMAX.LT.CMINPS)NYOUT=.TRUE.                                  07310000
905   CURMAX=CURMIN                                                     07330000
      DO906L=1,NSOL                                                     07340000
      IF(ZSOL(L).LE.CURMAX)GOTO906                                      07350000
      CURMAX=ZSOL(L)                                                    07360000
      LMAX=L                                                            07370000
906   CONTINUE                                                          07380000
C                             ----------------------------------        07390000
      GOTO160                                                           07400000
C***********************   R E S U L T S   ***********************      07410000
 1000 I=ISC(CMINPS)                                                     07420000
      IF(NSOL.LE.0)GOTO1900                                             07430000
      ZWAT=.TRUE.                                                       07440000
      SAFSET=.TRUE.                                                     07450000
      STOSET=.TRUE.                                                     07460000
      NETOUT=.TRUE.                                                     07470000
      SURVEY=.FALSE.                                                    07480000
      J=ISC(CURMIN)                                                     07490000
      K=ISC(CURMAX)                                                     07500000
      WRITE(IW1,650)NSOL,J,K                                            07510000
      IF(.NOT.NYOUT)WRITE(IW1,651)K,I                                   07520000
      IF(NYOUT)WRITE(IW1,652)K,I,MAXSOL                                 07530000
      CALLIRANK(ZSOL,O,NSOL)                                            07550000
      LMAX=0                                                            07560000
1005  LMAX=LMAX+1                                                       07570000
      I=O(LMAX)                                                         07580000
      J=ISC(ZSOL(I))                                                    07590000
      WRITE(IW1,655)LMAX,J                                              07600000
      J=IDSOL(I)                                                        07610000
      CALLDECODE(JOUT,NFAC,J,MTWO,NF)                                   07620000
      GOTO168                                                           07630000
1100  IF(LMAX.LT.NSOL)GOTO1005                                          07640000
      GOTO2000                                                          07650000
1900  WRITE(IW1,659)I                                                   07660000
2000  WRITE(IW1,660)FACSET,NSTOR,LINCAL,NOSMMR                          07670000
      READ(IR1,503)I                                                    07680000
      IF(I.NE.IEND)GOTO8                                                07690000
      WRITE(IW1,670)                                                    07700000
      RETURN                                                            07710000
C**************************   F O R M A T S   ************************  07720000
 0503 FORMAT(20A4)                                                      07730000
 509  FORMAT(5X,25I3)                                                   07740000
 600  FORMAT(16H1BEGINNING ALL02/1H0,20A4)                              07750000
 0625 FORMAT(15H READING SUBSET,35I3)                                   07760000
 626  FORMAT(67H1///////// A FACILITY SUBSET IS BEING DONE WITH NETOUT. 07770000
     *THIS IS THE,I10,27H  TH. SUBSET IN THE SURVEY./15H FACILITY NAMES)07780000
 650  FORMAT(24H1THE SURVEY IS FINISHED.,I10,52H SOLUTIONS HAVE BEEN RET07790000
     *AINED, WITH TOTAL COSTS FROM,I15,4H  TO,I15,2H .)                 07800000
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651  FORMAT(35H THERE WERE NO OTHER SOLUTIONS FROM,I15,4H  TO,I15,2H .)
652  FORMAT(31H THERE WERE SOME SOLUTIONS FROM,I15,4H  TO,I15,2H ,/45H 
     *BUT IT WAS SPECIFIED NOT TO RETAIN MORE THAN,I10,12H  SOLUTIONS.) 
655  FORMAT(26H1FACILITY COMBINATION RANK,I5,10X,10HTOTAL COST,I15)
0659 FORMAT(54H0NO SOLUTION IS STORED SINCE THE CRITERION CURMIN+EPS=,I
     *10,11H IS TOO LOW/1H ,22X,61HAND/OR ALL GIVEN FACILITY SUBSETS CON
     *TAINED UNUSED FACILITIES/1H ,22X,54HAND/OR NO GIVEN FACILITY SUBSE
     *T COULD MEET THE DEMAND.)
0660 FORMAT(12H1END OF CASE/13H STATISTICS..,6X,7HFACSET=,I10,5X,6HNSTO
     *R=,I10,5X,7HLINCAL=,I10,5X,7HNOSMMR=,I10)
670  FORMAT(13H0END OF ALLO2)
0712 FORMAT(79H0+++WARNING+++  WINTER OPTIMIZATION YIELDED SUMMER SYSTE
     *M INFEASIBLE FOR SUBSET/1H ,15X,25I3)
0800 FORMAT(80L1)
0801 FORMAT(40I2)
0802 FORMAT(8I10)
0803 FORMAT(10(8HRESTART ))
0804 FORMAT(20A4)
0805 FORMAT(6E13.6)
0806 FORMAT(6(1PE13.6))
0807 FORMAT(37H0***** DATA DUMP COMPLETED AT FACSET=,I10,8H   *****)
7601 FORMAT((1H ,15X,33HSUMMER DEAD-END . . . . . . . . . .,10(I3,A5)))
7602 FORMAT((1H ,15X,33HALL-YEAR INTERMEDIATE . . . . . . .,10(I3,A5)))
7604 FORMAT((1H ,15X,33HALL-YEAR DEAD-END . . . . . . . . .,10(I3,A5)))
7605 FORMAT((1H ,15X,33HWINTER STORAGE  . . . . . . . . . .,10(I3,A5)))
7607 FORMAT(22H INTERMEDIATE FACILITY,I3,A5,37H SENDS ITS SLUDGE TO DEA
     *DEND FACILITY,I3,A5)
7608 FORMAT(1H0,64X,16HTOTAL FIXED COST,I15/39H0WINTER AND ALL-YEAR POR
     *TIONS OF SYSTEM/1H0,30X,27HSLUDGE DISTRIBUTION PATTERN/)
7610 FORMAT(1H0,56X,19HTOTAL VARIABLE COST,I15/1H ,56X,24HSYSTEM COST T
     *OTAL SO FAR,I15)
7611 FORMAT(60H THERE IS NO SPECIAL SUMMER PORTION OF SYSTEM.. THIS IS 
     *ALL.)
7613 FORMAT(25H0SUMMER PORTION OF SYSTEM/1H0,30X,27HSLUDGE DISTRIBUTION
     * PATTERN)
7615 FORMAT(1H0,56X,19HTOTAL VARIABLE COST,I15/1H ,63X,17HSYSTEM COST T
     *OTAL,I15)
7616 FORMAT(66H THIS COMBINATION IS ALREADY STORED WITHOUT THE UNUSED F
     *ACILITIES.)
7707 FORMAT(51H0NETOUT TERMINATED.. NO USEFUL FACILITIES IN SUBSET)
7708 FORMAT(61H0NETOUT TERMINATED.. SUFFICIENT WINTER CAPACITY NOT AVAI
     *LABLE)
7709 FORMAT(61H0NETOUT TERMINATED.. SUFFICIENT SUMMER CAPACITY NOT AVAI
     *LABLE)
C=======================================================================
      END
      BLOCKDATA
      COMMON/LAYDAT/NN(10),IR1,IW1,IR2,IW2,ILP1(30),ILP2(30),JLP(30),LFP
     *P(30),JOUT(30),IH(8)/INLARB/INLARS(1435)/INSMAB/INSMAS(123)/ACONVB
     */ACONVS(40)/REALB/REALS(731)/LOGICB/LOGICS(1024)
      INTEGERACONVS
      LOGICALLOGICS
      DATALOGICS/1024*.FALSE./,INSMAS/123*0/,INLARS/1435*999999999/,ACON
     *VS/40*4HDASH/,REALS/731*0.0/,IR1,IW1,IR2,IW2/5,6,8,9/,IH/4H SOU,4H
     *RCE ,4H STO,4HRAGE,4H  TO,4HTAL ,4HAM T,4HO LF/
      END
      SUBROUTINESTART
      COMMON/STARTB/ALPHA,TITLE(20),W(80),MFC1(4),OAMF(30),KF(30),JCOF(2
     *0),HAULF(9),HAULV(9)
      COMMON/LAYDAT/ISMMR,SUMMER,MPP0,MLQ0,MLF0,MLF1,MLFN,MPPN,MHT,NFAC,
     *IR1,IW1,IR2,IW2,ILP1(30),ILP2(30),JLP(30),LFPP(30),JOUT(30),IH(8)
      COMMON/INLARB/NSTOR,NOSMMR,LINCAL,NS2,NS3,NS4,NHT2,NHT3,NHT4,NPP2,
     *NPP3,NPP4,INF,NSETS,EPS,IEPS,IDEFIN,NEXSET,ARBOUT,FACSET,NEXPUN,NF
     *RTAB,NSOL,MAXSOL,CURMIN,CURMAX,OLDMAX,CMINPS,SUMQ,IWINT,IWINT2,ISU
     *MM,IWFAC,ISCUAN,IDUMP,CONF(30),CAP(30),CTRANS(10,30),CTRANL(10,20)
     *,CTRANP(10,20),Q(10),IOSOL(20),ZSOL(20),MTWO(30),BAR(30),OLDBAR(30
     *),KTRANS(10,30),KTRANP(10,20)
      COMMON/INSMAB/KASCNT,NF,NS,NLS,NPP,NLF,NHT,NLS1,NLSN,NPP1,NPPN,NLF
     *1,NLFN,NHT1,NHTN,SIZE,MSIZ,NFN,LTAB,RTAB,ITAB,OTAB,NTAB,ITYP,LMAX,
     *MAXSIZ(4),NAVA(30),OLNAVA(30),IYP(30),MFC(4)
      COMMON/ACONVB/NAMSRC(10),NAMFAC(30)
      COMMON/REALB/SCALE,DISTNS(10,30),DISTNL(10,20),DISTNP(10,20),VRED(
     *30)
      COMMON/LOGICB/LCTNLO,LCTNPO,NLSO,NPPO,NLFO,NHTO,IDEFO,STOSET,SAFSE
     *T,HTINC,LFINC,LSINC,PPINC,LSHTIN,PPLFIN,L00,L01,               L00
     *PPN,LSCHTO,PCFOL1,HTSUPF,LFSUPF,HTESSN,LFESSN,SIZE1,NFNSIZ,SIZMTY,
     *SNINC,MORE,NYOUT,NOBLOC(900),INC(30),COND(4),MSET(30),SUPF(30)
      INTEGEREPS,ARBOUT,FACSET,CURMIN,CURMAX,OLDMAX,CMINPS,SUMQ,CONF,CAP
     *,CTRANS,CTRANL,CTRANP,Q,ZSOL,SIZE,RTAB,OTAB,BAR,OLDBAR,OLNAVA
      INTEGERISAY(18),TITLE,OAMF
      LOGICAL      LCTNLO,LCTNPO,NLSO,NPPO,NLFO,NHTO,IDEFO,STOSET,SAFSET
     *,HTINC,LFINC,LSINC,PPINC,LSHTIN,PPLFIN,L00,L01,               L00P
     *PN,LSCHTO,PCFOL1,HTSUPF,LFSUPF,HTESSN,LFESSN,SIZE1,NFNSIZ,SIZMTY,S
     *NINC,MORE,NYOUT,NOBLOC,INC,COND,MSET,SUPF,COORD,DIST,COST
      DIMENSIONY(4,10),XS(10),YS(10),XF(30),YF(30),OAMV(30),CONV(30)
      EQUIVALENCE(W(1),Y(1,1)),(W(1),CONV(1)),(W(31),OAMV(1)),(ISAY(1),T
     *ITLE(1)),(W(1),XS(1)),(W(11),YS(1)),(W(21),YF(1)),(W(51),XF(1))
      DATAICST,IDST/4HICST,4HIDST/
      KFIX(R)=IFIX(R+0.5)
      JSC(I)=KFIX(SCALE*FLOAT(I))
      IF(KASCNT.GT.0)GOTO26
C****************  A L L O    S T A R T  *********************
      READ(IR1,500)NS,NLS,NPP,NLF,NHT
      WRITE(IW1,6000)NS,NLS,NPP,NLF,NHT
      NLSO=NLS.EQ.0
      NPPO=NPP.EQ.0
      NLFO=NLF.EQ.0
      NHTO=NHT.EQ.0
C                                         ----- TAB-SETTING ROUTINE ----
      NLS1=1
      IF(NLSO)NLS1=0
      NLSN=NLS
      NPP1=NLSN
      IF(.NOT.NPPO)NPP1=NLSN+1
      NPPN=NLSN+NPP
      NLF1=NPPN
      IF(.NOT.NLFO)NLF1=NPPN+1
      NLFN=NPPN+NLF
      NHT1=NLFN
      IF(.NOT.NHTO)NHT1=NLFN+1
      NHTN=NLFN+NHT
      NF=NHTN
      NPP4=4*NPP
      NPP3=NPP4-1
      NPP2=NPP3-1
      NS4=4*NS
      NS3=NS4-1
      NS2=NS3-1
      NHT4=4*NHT
      NHT3=NHT4-1
      NHT2=NHT3-1
      LCTNLO=NLSO.OR.NHTO
      LCTNPO=NPPO.OR.NLFO
C                                        ---------------------------
      WRITE(IW1,6001)
      DO9J=1,NS
      READ(IR1,501)I,NAMSRC(I),ISAY
      WRITE(IW1,6002)I,NAMSRC(I),ISAY
      WRITE(IW1,60025)
      DO10J=1,NF
      READ(IR1,501)I,NAMFAC(I),ISAY
 0010 WRITE(IW1,6002)I,NAMFAC(I),ISAY
      READ(IR1,507)ALPHA
      WRITE(IW1,6003)ALPHA
      IF(ALPHA.LT.0.0001)GOTO24
C.........READ IN COORDINATES FOR DISTANCE CALCULATIONS
      WRITE(IW1,6004)
      DO15I=1,NS
      READ(IR1,507)XS(I),YS(I)
 15   WRITE(IW1,601)I,XS(I),YS(I)
      DO16J=1,NF
      READ(IR1,507)XF(J),YF(J)
 16   WRITE(IW1,601)J,XF(J),YF(J)
      DO17I=1,NS
      XSI=XS(I)
      YSI=YS(I)
      DO17J=1,NF
      XFS=XF(J)-XSI
      YFS=YF(J)-YSI
 17   DISTNS(I,J)=ALPHA*SQRT(XFS*XFS+YFS*YFS)
      IF(LCTNLO)GOTO21
      DO19I=NHT1,NHTN
      XSI=XF(I)
      YSI=YF(I)
      I1=I-NLFN
      DO19J=1,NLS
      XFS=XF(J)-XSI
      YFS=YF(J)-YSI
 19   DISTNL(I1,J)=ALPHA*SQRT(XFS*XFS+YFS*YFS)
 21   IF(LCTNPO)GOTO24
      DO22J=NLF1,NLFN
      XSI=XF(J)
      YSI=YF(J)
      J1=J-NPPN
      DO22I=NPP1,NPPN
      XFS=XSI-XF(I)
      YFS=YSI-YF(I)
      I1=I-NLS
 0022 DISTNP(I1,J1)=ALPHA*SQRT(XFS*XFS+YFS*YFS)
 0024 READ(IR1,502)EPS,MAXSOL
      WRITE(IW1,602)EPS,MAXSOL
      CALLM2VEC(MTWO,NF)
      NSETS=MTWO(NF)+MTWO(NF)-1
      M=NS+1
C********************** C A S E   S T A R T *******************
 0026 KASCNT=KASCNT+1
      READ(IR1,503)TITLE
      WRITE(IW1,603)KASCNT,TITLE
      READ(IR1,504)(Q(I),I=1,NS)
      WRITE(IW1,604)(I,NAMSRC(I),Q(I),I=1,NS)
      SUMQ=0
      ISCUAN=0
      DO30I=1,NS
      J=Q(I)
      IF(J.GT.ISCUAN)ISCUAN=J
0030  SUMQ=SUMQ+J
      K=NOLIM(SUMQ)
      DO31J=1,NF
      READ(IR1,505)CAP(J),CONF(J),CONV(J),OAMF(J),OAMV(J),VRED(J)
      IF(CAP(J).LE.0.OR.CAP(J).GT.K)CAP(J)=K
 0031 CONTINUE
      WRITE(IW1,6041)
0032  WRITE(IW1,605)(J,NAMFAC(J),CAP(J),CONF(J),CONV(J),OAMF(J),OAMV(J),
     *VRED(J),J=1,NF)
      READ(IR1,506)L,WINTER
      WRITE(IW1,606)L,WINTER
      L00=L.EQ.0
      L01=.NOT.L00
      ISCONF=0
      DO35J=1,NF
      OAMV(J)=OAMV(J)+CONV(J)
      CONF(J)=CONF(J)+OAMF(J)
0035  ISCONF=ISCONF+CONF(J)
      READ(IR1,503)I
      WRITE(IW1,609)I
      DIST=I.EQ.IDST
      COST=I.EQ.ICST
      COORD=.NOT.DIST.AND..NOT.COST
      IF(COST)GOTO355
      READ(IR1,509)N,(I,HAULF(I),HAULV(I),J=1,N)
      WRITE(IW1,613)(I,HAULF(I),HAULV(I),I=1,N)
0355  WRITE(IW1,6091)
      IF(.NOT.COST)GOTO361
      N=MAX0(NS,NHT,NPP)
      DO36I=1,N
0036  Y(2,I)=0.0
0361  ISCOEF=0
C........CALCULATE DISTRIBUTION COST ARRAYS ACCORDING TO COORD,DIST,COST
C.........FIRST,SOURCES TO FACILITIES
      DO37I=1,NS
37    Y(1,I)=FLOAT(I)
      DO40J=1,NF
      OAMVJ=OAMV(J)
      IF(COST)GOTO373
      READ(IR1,5075)(JCOF(I),I=1,NS)
      WRITE(IW1,6101)(JCOF(I),I=1,NS)
      IF(DIST)READ(IR1,507)(W(I),I=2,NS2,4)
      GOTO375
 0373 READ(IR1,507)(W(I),I=3,NS3,4)
0375  DO39I=1,NS
      IF(COST)GOTO38
      IF(COORD)Y(2,I)=DISTNS(I,J)
      Y(3,I)=HAULF(JCOF(I))+HAULV(JCOF(I))*Y(2,I)
38    Y(4,I)=Y(3,I)+OAMVJ
      I1=IFIX(1.E7*Y(4,I)+0.5)
      IF(I1.GT.ISCOEF)ISCOEF=I1
0039  CTRANS(I,J)=I1
0040  WRITE(IW1,610)J,(W(I),I=1,NS4)
C........HT TO LS
      IF(LCTNL0)GOTO46
      DO41I=1,NHT
41    Y(1,I)=FLOAT(I+NLFN)
      DO45J=1,NLS
      OAMVJ=OAMV(J)
      IF(COST)GOTO415
      READ(IR1,5075)(JCOF(I),I=1,NHT)
      WRITE(IW1,6101)(JCOF(I),I=1,NHT)
      IF(DIST)READ(IR1,507)(W(I),I=2,NHT2,4)
      GOTO42
0415  READ(IR1,507)(W(I),I=3,NHT3,4)
0042  DO44I=1,NHT
      IF(COST)GOTO43
      IF(COORD)Y(2,I)=DISTNL(I,J)
      Y(3,I)=HAULF(JCOF(I))+HAULV(JCOF(I))*Y(2,I)
0043  Y(4,I)=Y(3,I)+OAMVJ
      I1=IFIX(1.E7*Y(4,I)+0.5)
      IF(I1.GT.ISCOEF)ISCOEF=I1
0044  CTRANL(I,J)=I1
0045  WRITE(IW1,611)J,(W(I),I=1,NHT4)
C.........PP TO LF
 46   IF(LCTNPO)GOTO60
      DO47I=1,NPP
47    Y(1,I)=FLOAT(I+NLSN)
      DO51J=1,NLF
      J1=J+NPPN
      OAMVJ=OAMV(J1)
      IF(COST)GOTO475
      READ(IR1,5075)(JCOF(I),I=1,NPP)
      WRITE(IW1,6101)(JCOF(I),I=1,NPP)
      IF(DIST)READ(IR1,507)(W(I),I=2,NPP2,4)
      GOTO48
 0475 READ(IR1,507)(W(I),I=3,NPP3,4)
0048  DO50I=1,NPP
      IF(COST)GOTO49
      IF(COORD)Y(2,I)=DISTNP(I,J)
      Y(3,I)=HAULF(JCOF(I))+HAULV(JCOF(I))*Y(2,I)
0049  Y(4,I)=Y(3,I)+OAMVJ
      I1=IFIX(1.E7*Y(4,I)+0.5)
      IF(I1.GT.ISCOEF)ISCOEF=I1
0050  CTRANP(I,J)=I1
0051  WRITE(IW1,611)J1,(W(I),I=1,NPP4)
0060  SCALE=1.E5
      U=0.1*FLOAT(INF)
      S=FLOAT(SUMQ)
      R=FLOAT(ISCOEF)
      V=FLOAT(ISCUAN)
      SCONF=1.E7*FLOAT(ISCONF)
 0061 SCOEF=(SCALE*R)/U
      SCUAN=SCALE*(V/U)
      WFAC=(2.0*R*S+SCONF)/U
      IF(SCOEF*SCUAN.GE.WFAC)GOTO63
      RWFAC=SQRT(WFAC)
      IF(SCOEF.LE.SCUAN)GOTO62
      IF(RWFAC.GT.SCOEF)SCOEF=RWFAC
      SCUAN=WFAC/SCOEF
      GOTO63
0062  IF(RWFAC.GT.SCUAN)SCUAN=RWFAC
      SCOEF=WFAC/SCUAN
 0063 IF(SCALE.LT.60.0.OR.(R/SCOEF.GT.1.E4.AND.V/SCUAN.GT.1.E4))GOTO64
      SCALE=0.9*SCALE
      GOTO61
 0064 ISCOEF=IROUND(KFIX(2.0*SCOEF))
      ISCUAN=IROUND(KFIX(2.0*SCUAN))
      IWFAC=IROUND(KFIX(2.0*SCALE))
      ISCOE2=ISCOEF/2
      ISCUA2=ISCUAN/2
      IWFAC2=IWFAC/2
      IWINT=MAX1(1.0,WINTER*FLOAT(IWFAC))
      IWINT2=IWINT/2
      ISUMM=IWFAC-IWINT
      L=10000000/ISCOEF
      SCALE=1.E7/(FLOAT(ISCOEF)*FLOAT(ISCUAN))
      READ(IR1,507)S
      IF(S.LE.13.287712)GOTO65
      IWF=100
      IWFD=1
      IWFD2=0
      GOTO68
65    R=S
      IWF=KFIX(1.E3*(2.0**(S/2.0)))
      IWFD=1000
0066  IF(IWF.LE.100)GOTO67
      IWF=(IWF+5)/10
      IWFD=(IWFD+5)/10
      IF(IWFD.GT.1)GOTO66
0067  IWFD2=IWFD/2
0068  WRITE(IW1,6111)L,ISCUAN,SCALE,IWINT,IWFAC,R,IWF,IWFD
      DO71I=1,NF
0071  CAP(I)=(CAP(I)+ISCUA2)/ISCUAN
      DO72J=1,NF
      DO72I=1,NS
      CTRANS(I,J)=(CTRANS(I,J)+ISCOE2)/ISCOEF
0072  KTRANS(I,J)=CTRANS(I,J)
      IF(LCTNL0)GOTO074
      DO73J=1,NLS
      DO73I=1,NHT
0073  CTRANL(I,J)=(CTRANL(I,J)+ISCOE2)/ISCOEF
0074  IF(LCTNP0)GOTO76
      DO75J=1,NLF
      DO75I=1,NPP
0075  CTRANP(I,J)=(CTRANP(I,J)+ISCOE2)/ISCOEF
0076  SUMQ=0
      DO80I=1,NS
      Q(I)=(((Q(I)+ISCUA2)/ISCUAN)*IWINT+IWFAC2)/IWFAC
 0080 SUMQ=SUMQ+Q(I)
C........FINISH MODIFICATION OF DISTRIBUTION COST ARRAY
      IF(LCTNP0)GOTO99
      DO90J=1,NLF
      DO90I=1,NPP
      KTRANP(I,J)=(IWF*CTRANP(I,J)+IWFD2)/IWFD
0090  CTRANP(I,J)=(IWFAC*CTRANP(I,J)+IWINT2)/IWINT
0099  IF(L00)GOTO100
      L=NLFN
      GOTO101
 0100 IF(NPP0)GOTO103
      L=NPPN
0101  K=NLSN+1
      R=FLOAT(IWINT)/FLOAT(IWFAC)
      DO102J=K,L
      CAP(J)=KFIX(R*FLOAT(CAP(J)))
      DO102I=1,NS
      KTRANS(I,J)=(IWF*CTRANS(I,J)+IWFD2)/IWFD
0102  CTRANS(I,J)=(IWFAC*CTRANS(I,J)+IWINT2)/IWINT
      IEPS=JSC(EPS)
      DO1025J=1,NF
1025  CONF(J)=JSC(CONF(J))
103   READ(IR1,508)IDEFIN,ARBOUT,IDUMP,CURMIN
      IDEFO=IDEFIN.EQ.0
      IF(IDEFO)WRITE(IW1,615)NSETS,ARBOUT
      IF(.NOT.IDEFO)WRITE(IW1,616)IDEFIN,ARBOUT
      IF(IDUMP.GT.0)GOTO1035
      IDUMP=INF
      GOTO1038
1035  WRITE(IW1,6165)IDUMP
 1038 IF(CURMIN.LE.0)GOTO0104
      CURMIN=JSC(CURMIN)
      CMINPS=CURMIN+IEPS
      GOTO1045
0104  CURMIN=INF
      CMINPS=INF
1045  OLDMAX=INF
      WRITE(IW1,617)CURMIN
      FACSET=0
      NSOL=0
      NSTOR=0
      LINCAL=0
      NOSMMR=0
      SAFSET=IDEFO
      STOSET=.FALSE.
      NYOUT=.FALSE.
      NEXSET=ARBOUT
      NEXPUN=IDUMP
      IF(.NOT.IDEFO)RETURN
C INITIALIZE COMBEX
      INFB2=INF/2
      IF(NLSO)GOTO0108
      DO0106I=NLS1,NLSN
0106  IYP(I)=1
 0108 IF(NPPO)GOTO0112
      DO0110I=NPP1,NPPN
0110  IYP(I)=2
0112  IF(NLFO)GOTO0116
      DO0114I=NLF1,NLFN
0114  IYP(I)=3
0116  IF(NHTO)GOTO0120
      DO0118I=NHT1,NHTN
0118  IYP(I)=4
0120  DO0122I=1,NF
0122  INC(I)=.FALSE.
 0124 READ(IR1,500)I
      IF(I.EQ.0)GOTO0126
      WRITE(IW1,620)I,NAMFAC(I)
      INC(I)=.TRUE.
      GOTO0124
0126  M=NF*NF
      DO0128I=1,M
0128  NOBLOC(I)=.TRUE.
0130  READ(IR1,500)K,L
      IF(K.EQ.0.OR.L.EQ.0)GOTO0140
      WRITE(IW1,621)K,NAMFAC(K),L,NAMFAC(L)
      I=NF*(K-1)+L
      NOBLOC(I)=.FALSE.
      I=NF*(L-1)+K
      NOBLOC(I)=.FALSE.
      INC(K)=.FALSE.
      INC(L)=.FALSE.
      GOTO0130
0140  DO0150I=1,4
0150  MFC1(I)=0
      DO0160I=1,NF
      J=IYP(I)
      IF(INC(I))MFC1(J)=MFC1(J)+1
0160  CONTINUE
      LSINC=MFC1(1).GT.0
      PPINC=MFC1(2).GT.0
      LFINC=MFC1(3).GT.0
      HTINC=MFC1(4).GT.0
      NINC=MFC1(1)+MFC1(2)+MFC1(3)+MFC1(4)
      NFN=NF-NINC
      DO0170I=1,NF
      IF(.NOT.INC(I))GOTO0180
0170  CONTINUE
0180  LTAB=I
      J=NF
      DO0190I=1,NF
      IF(.NOT.INC(J))GOTO0200
0190  J=J-1
0200  RTAB=J
      NFRTAB=NF*RTAB
      READ(IR1,500)MAXSIZ
      WRITE(IW1,622)MAXSIZ
      ICOUNT=0
      SIZE=0
      LOOPPN=LOO.AND..NOT.PPINC
      LSCHTO=LSINC.OR.NHTO
      PCFOL1=NLFO.OR..NOT.LOOPPN
      LSHTIN=LSINC.AND.HTINC
      PPLFIN=PPINC.AND.LFINC
      HTESSN=.FALSE.
      LFESSN=.FALSE.
      DO1610I=1,4
1610  MFC(I)=0
      DO1611I=1,NF
      JOUT(I)=0
      OLDBAR(I)=0
      IF(INC(I))OLDBAR(I)=INFB2
1611  MSET(I)=.FALSE.
      L=0
      J=NF
      DO1615I=1,NF
      OLNAVA(J)=L
      IF(OLDBAR(J).EQ.0)L=L+1
1615  J=J-1
      IF(.NOT.LSHTIN)GOTO1612
      COND(1)=.TRUE.
      COND(4)=.TRUE.
1612  IF(.NOT.PPLFIN)RETURN
      COND(2)=.TRUE.
      COND(3)=.TRUE.
      RETURN
```

```
0500 FORMAT(5(7X,I3))
0501 FORMAT(I2,2X,19A4)
0502 FORMAT(5X,I10,5X,I10,10X,I5)
0503 FORMAT(20A4)
504  FORMAT(5(5X,I10))
0505 FORMAT(5X,I10,2(5X,I10,E10.0),5X,E10.0)
506  FORMAT(5X,I1,14X,F10.9)
507  FORMAT(10X,7F10.6)
5075 FORMAT(10X,7I10)
508  FORMAT(4(10X,I10))
0509 FORMAT(I5/3(I5,2E10.0))
6000 FORMAT(19HONUMBER OF SOURCES ,I2/21HONUMBER OF FACILITIES/1H0,15X,
    *37HSUMMER DEAD-END . . . . . . . . . . .,I4/1H ,15X,37HALL-YEAR IN
    *TERMEDIATE . . . . . . . . .,I4/1H ,15X,37HALL-YEAR DEAD-END . . . .
    * . . . . . .,I4/1H ,15X,37HWINTER STORAGE  . . . . . . . . . . . .,I
    *4)
6001 FORMAT(22HOSOURCE NAMES USED ARE/)
6002 FORMAT(1H ,10X,I2,2X,A4,4X,18A4)
60025 FORMAT(24HOFACILITY NAMES USED ARE/)
6003 FORMAT(19HOTRAVELLING FACTOR ,F10.6)
6004 FORMAT(12HOCOORDINATES/)
601  FORMAT(1H ,I2,3H X=,F10.3,3H Y=,F10.3)
0602 FORMAT(5HOEPS=,I10,5X,7HMAXSOL=,I5)
0603 FORMAT(12H1CASE NUMBER,I3/1H0,20A4)
604  FORMAT(29HOANNUAL PRODUCTION AT SOURCES,8X,4(I2,1X,A4,I11,5X)/(1H
    *,36X,4(I2,1X,A4,I11,5X)))
6041 FORMAT(20HOFACILITY PARAMETERS,17X,3HLIM,11X,4HCONF,11X,4HCONV,11X
    *,4HOAMF,11X,4HOAMV,11X,4HVRED)
605  FORMAT((1H ,18X,I2,A5,4X,2(I10,5X),1PE10.3,5X,I10,2(5X,1PE10.3)))
606  FORMAT(7HOLIQLF=,I1,9H  WINTER=,F10.8)
0609 FORMAT(48HOMODE OF DISTRIBUTION COST ARRAY CALCULATION IS ,A4)
6091 FORMAT(1H0,27X,2(15X,20HUNI TRANS  UNIT VARI)/1H ,27X,2(5X,30HDIST
    *ANCE  PORT COST  ABLE COST))
610  FORMAT(12H TO FACILITY,I3,14H FROM SOURCE  ,2(F4.0,F8.4,2F11.4)/(1
    *H ,28X,2(F4.0,F8.4,2F11.4)))
6101 FORMAT(24H USING HAULAGE FORMULA..,2(I8,26X)/(1H ,23X,2(I8,26X)))
611  FORMAT(12H TO FACILITY,I3,14H FROM FACILITY,2(F4.0,F8.4,2F11.4)/(1
    *H ,28X,2(F4.0,F8.4,2F11.4)))
6111 FORMAT(56HOFOR COMPUTATION THE DATA IS BEING MODIFIED AS FOLLOWS..
    */33HOVARIABLE COSTS ARE MULTIPLIED BY,I10/
    *                                        44H SLUDGE QUANTITIES AND L
    *IMITS ARE DIVIDED BY,I10/30H FIXED COSTS ARE MULTIPLIED BY,1PE14.7
    */63H THE WINTER FACTOR IS CONVERTED TO THE RATIO OF THE TWO NUMBER
    *S,I10,6H  OVER,I10/39H THE WEIGHTING FACTOR THAT WAS READ IN,,F14.
    *7,1H,/ 62H  YIELDS MULTIPLICATION OF VARIABLE ALL-YEAR FACILITY CO
    *STS BY,I4,6H  OVER,I4/ 55H  FOR PURPOSES OF COST COMPARISON IN THE
    * WINTER SYSTEM./82H FOR EASY READING ALL SOLUTIONS WILL BE PRINTED
    * OUT IN TERMS OF THE ORIGINAL DATA.)
0613 FORMAT(25H HAULAGE FORMULAS . . . ./(1H ,I2,23H COST PER UNIT VOLU
    *ME =,1PE12.4,5H PLUS,1PE12.4,18H TIMES TRIP LENGTH))
615  FORMAT(11H1ALL OF THE,I10,57H  POSSIBLE COMBINATIONS OF FACILITIES
    * WILL BE CONSIDERED./6H EVERY,I10,65H TH. COMBINATION REACHING THE
    * SURVEY WILL BE DONE WITH NETOUT FOR/86H DETAILED TREATMENT INCLUD
    *ING PRINTOUT OF BEST SLUDGE DISTRIBUTION PATTERNS AND COSTS.)
616  FORMAT(1H1,I10,59H  COMBINATIONS OF FACILITIES WILL BE READ IN AND
    * EVALUATED./6H EVERY,I10,53H TH. COMBINATION READ IN WILL BE DONE
    *WITH NETOUT FOR/86H DETAILED TREATMENT INCLUDING PRINTOUT OF BEST
    *SLUDGE DISTRIBUTION PATTERNS AND COSTS.)
6165 FORMAT(37H DATA DUMP WILL OCCUR AT INTERVALS OF,I10)
0617 FORMAT(63HOCOST SURVEY BEGINNING WITH CURRENT MINIMUM TOTAL SYSTEM
    * COST =,I10)
0620 FORMAT(9H FACILITY,I3,A4,33H IS INCLUDED IN EVERY COMBINATION)
0621 FORMAT(11H FACILITIES,I3,A5,4H AND,I3,A5,32H ARE NOT BOTH IN ANY C
    *OMBINATION)
0622 FORMAT(67H0THE MAXIMUM NUMBER OF FACILITIES OF ONE KIND IN ANY COM
    *BINATION IS/1H ,15X,I2,15H SUMMER DEADEND/1H ,15X,I2,22H ALL-YEAR
    *INTERMEDIATE/1H ,15X,I2,17H ALL-YEAR DEADEND/1H ,15X,I2,15H WINTER
    * STORAGE)
     END
     SUBROUTINELINPRO
     COMMON/LINDAT/NL(320),G(16),LISTU(16),NLV(16),LS(320),R(20),LISTV(
    *20),LSV(20),A(16),B(20),C(16,20),X(16,20),KWC(16,20),CRIT,KW,M,N,Z
    *WAT
     COMMON/INLARB/LL(2),LINCAL,NN(9),INF,MM(22),CONF(30),CAP(30),CTRAN
    *S(10,30),CTRANL(10,20),CTRANP(10,20),Q(10),IDSOL(20),ZSOL(20),MTWO
    *(30),BAR(30),OLDBAR(30),KTRANS(10,30),KTRANP(10,20)
     INTEGERG,H,R,S,T,TAB,U,V,CRIT,A,B,C,X,GD,CIJ,BJ,AI,XIJ
     LOGICALZWAT,IZGO
     LINCAL=LINCAL+1
     DO13I=1,M,1
     NLV(I)=N*(I-1)
     DO13J=1,N,1
13   X(I,J)=0
     DO15J=1,N,1
     LISTV(J)=1
15   LSV(J)=M*(J-1)
     KW=0
     GD=0
     DO20I=1,M,1
     H=INF
     DO18J=1,N,1
18   IF(C(I,J).LT.H)H=C(I,J)
     DO19J=1,N,1
     CIJ=C(I,J)-H
     C(I,J)=CIJ
     IF(CIJ.GT.0)GOTO19
     LISTV(J)=0
     NLVI=NLV(I)+1
     NLV(I)=NLVI
     NL(NLVI)=J
0019 CONTINUE
0020 CONTINUE
 201 DO23J=1,N,1
     IF(LISTV(J).EQ.0)GOTO23
     H=INF
     DO21I=1,M,1
21   IF(C(I,J).LT.H)H=C(I,J)
     DO22I=1,M,1
     CIJ=C(I,J)-H
     C(I,J)=CIJ
     IF(CIJ.GT.0)GOTO22
     NLVI=NLV(I)+1
     NLV(I)=NLVI
     NL(NLVI)=J
0022 CONTINUE
23   CONTINUE
     DO27I=1,M,1
     AI=A(I)
     NLVI=NLV(I)
     TAB=N*(I-1)+1
```

```
      DO25U=TAB,NLVI,1
      J=NL(U)
      BJ=B(J)
      IF(BJ.LE.0)GOTO25
      H=BJ
      IF(AI.LT.BJ)H=AI
      X(I,J)=H
      AI=AI-H
      B(J)=BJ-H
      LSVJ=LSV(J)+1
      LS(LSVJ)=I
      LSV(J)=LSVJ
      IF(AI.LE.0)GOTO26
25    CONTINUE
26    A(I)=AI
27    GD=GD+AI
 28   IF(GD.LE.0)RETURN
 29   DO30J=1,N,1
30    R(J)=0
      K=0
      DO32I=1,M,1
      IF(A(I).LE.0)GOTO31
      K=K+1
      LISTU(K)=I
      G(I)=INF
      GOTO32
31    G(I)=0
32    CONTINUE
 33   L=0
      DO34U=1,K,1
      I=LISTU(U)
      NLVI=NLV(I)
      TAB=N*(I-1)+1
      DO34S=TAB,NLVI,1
      J=NL(S)
      IF(R(J).NE.0)GOTO34
      R(J)=I
      L=L+1
      LISTV(L)=J
      IF(B(J).GT.0)GOTO36
34    CONTINUE
      IF(L.EQ.0)GOTO45
      K=0
      DO35V=1,L,1
      J=LISTV(V)
      LSVJ=LSV(J)
      TAB=M*(J-1)+1
      DO35S=TAB,LSVJ,1
      I=LS(S)
      IF(G(I).NE.0)GOTO35
      G(I)=J
      K=K+1
      LISTU(K)=I
35    CONTINUE
      IF(K.EQ.0)GOTO45
      GOTO33
 36   H=B(J)
      TAB=J
37    I=R(J)
      J=G(I)
      IF(J.EQ.INF)GOTO38
      IF(X(I,J).LT.H)H=X(I,J)
      GOTO37
38    IF(A(I).LT.H)H=A(I)
      J=TAB
      B(J)=B(J)-H
      A(I)=A(I)-H
      GD=GD-H
40    I=R(J)
      XIJ=X(I,J)
      X(I,J)=XIJ+H
      IF(XIJ.GT.0)GOTO41
      LSVJ=LSV(J)+1
      LS(LSVJ)=I
      LSV(J)=LSVJ
 41   J=G(I)
      IF(J.EQ.INF)GOTO28
      XIJ=X(I,J)-H
      X(I,J)=XIJ
      IF(XIJ.GT.0)GOTO40
      LSVJ=LSV(J)
      TAB=M*(J-1)+1
      DO42T=TAB,LSVJ,1
      IF(LS(T).NE.I)GOTO42
      S=T
      GOTO43
42    CONTINUE
43    LSVJ=LSVJ-1
      IF(LSVJ.LT.S)GOTO54
      DO44T=S,LSVJ,1
44    LS(T)=LS(T+1)
54    LSV(J)=LSVJ
      GOTO40
 45   K=0
      L=N+1
      DO47J=1,N,1
      IF(R(J).NE.0)GOTO46
      K=K+1
      LISTV(K)=J
      GOTO47
 46   L=L-1
      LISTV(L)=J
47    CONTINUE
      H=INF
      DO48I=1,M,1
      IF(G(I).EQ.0)GOTO48
52    DO53S=1,K,1
      J=LISTV(S)
 53   IF(C(I,J).LT.H)H=C(I,J)
48    CONTINUE
 0485 DO51I=1,M
      IZG0=G(I).EQ.0
      NLVI=N*(I-1)
      DO49S=L,N,1
      J=LISTV(S)
      IF(IZG0)CIJ=C(I,J)+H
      IF(.NOT.IZG0)CIJ=C(I,J)
      C(I,J)=CIJ
      IF(CIJ.GT.0)GOTO49
      NLVI=NLVI+1
      NL(NLVI)=J
49    CONTINUE
      DO50S=1,K,1
      J=LISTV(S)
      IF(.NOT.IZGO)CIJ=C(I,J)-H
      IF(IZGO)CIJ=C(I,J)
      C(I,J)=CIJ
      IF(CIJ.GT.0)GOTO50
      NLVI=NLVI+1
      NL(NLVI)=J
50    CONTINUE
 51   NLV(I)=NLVI
      GOTO29
      END
      SUBROUTINELAYOUT
      COMMON/LINDAT/NL(320),INTG(16),LISTU(16),NLV(16),LS(320),INTR(20),
     *LISTV(20),LSV(20),A(16),B(20),C(16,20),X(16,20),KWC(16,20),CRIT,KW
     *,M,N,ZWAT
      COMMON/LAYDAT/ISUMMR,SUMMER,MPPO,MLQO,MLFO,MLF1,MLFN,MPPN,MHT,NFAC
     *,IR1,IW1,IR2,IW2,ILP1(30),ILP2(30),JLP(30),LFPP(30),JOUT(30),IHSOU
     *,IHRCE,IHHLD,IHTK,IHTG,IHTAL,IHAMT,IHOLF
      COMMON/INLARB/KK(29),IWINT,IWINT2,ISUMM,IWFAC,ISCUAN,IDUMP,
     *CONF(30),CAP(30),CTRANS(10,30),CTRANL(10,20),CTRANP(10,20),Q(10),I
     *DSOL(20),ZSOL(20),MTWO(30),BAR(30),OLDBAR(30),KTRANS(10,30),KTRANP
     *(10,20)
      COMMON/ACONVB/NAMSRC(10),NAMFAC(30)
      COMMON/REALB/SCALE,DISTNS(10,30),DISTNL(10,20),DISTNP(10,20),VRFD(
     *30)
      COMMON/LOGICB/NN(16),L01,MM(13),
     *     NOBLOC(900),INC(30),COND(4),MSET(30),SUPF(30)
      INTEGERIH(20),X,XSI
      LOGICALSUMMER,MPPO,MLQO,MORE,MLFO,L01
      EQUIVALENCE(IH(1),INTR(1))
      DO23I=1,NFAC
023   LS(I)=0
      LNBOL=0
      MBLK=5
      IF(SUMMER)MBLK=7
      L=M-1
      IF(SUMMER.OR.(MPPO.AND.MLQO))GOTO246
      I1=N-MHT
      DO244I=1,I1
      DO244J=1,L
      IF(X(J,I).LE.0)GOTO244
      X(J,I)=(X(J,I)*IWFAC+IWINT2)/IWINT
 0244 CONTINUE
0246  LNBLK=L-LNBOL
      IF(LNBLK.GT.MBLK)GOTO2463
      MORE=.FALSE.
      GOTO247
2463  MORE=.TRUE.
      IF(LNBLK.GT.8)GOTO2466
      LNBLK=MBLK
      GOTO247
2466  LNBLK=8
0247  LNBLK2=LNBLK*2
      IF(SUMMER)GOTO2471
      LNH=LNBLK2
      GOTO2472
2471  LNH=2*MAX0(0,ISUMMR-LNBOL)
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      IF(LNH.EQ.0)GOTO2474
 2472 DO2473I=2,LNH,2
      IH(I-1)=IHSOU
 2473 IH(I)=IHRCE
      IF(LNH.EQ.LNBLK2)GOTO2476
 2474 K=LNH+2
      LNH=LNBLK2
      DO2475I=K,LNH,2
      IH(I-1)=IHHLD
 2475 IH(I)=IHTK
 2476 IF(MORE)GOTO248
      IH(LNH+1)=IHTO
      LNH=LNH+2
      IH(LNH)=IHTAL
      IF(SUMMER.OR.MPPO)GOTO248
      IH(LNH+1)=IHAMT
      LNH=LNH+2
      IH(LNH)=IHOLF
 248  WRITE(IW1,6081)(IH(I),I=1,LNH)
      K=LNBOL+1
      LNBOL=LNBOL+LNBLK
      WRITE(IW1,6082)(ILP1(I),ILP2(I),I=K,LNBOL)
      DO26J=1,N
      J1=JLP(J)
      J2=JOUT(J1)
      DO25I=K,LNBOL
      NL(I)=ISCUAN*X(I,J)
 0025 LS(J1)=LS(J1)+NL(I)
      IF(MORE)GOTO252
      IF(SUMMER.OR.J1.GT.MPPN)GOTO251
      XSI=(IFIX(FLOAT(LS(J1))*VRED(J2)*1.E1)+5)/10
      I1=LFPP(J1)
      LS(I1)=LS(I1)+XSI
      I1=JOUT(I1)
      WRITE(IW1,6091)J2,NAMFAC(J2),(NL(I),I=K,LNBOL),LS(J1),XSI,I1
      GOTO26
 0251 WRITE(IW1,6091)J2,NAMFAC(J2),(NL(I),I=K,LNBOL),LS(J1)
      GOTO26
 0252 WRITE(IW1,6091)J2,NAMFAC(J2),(NL(I),I=K,LNBOL)
 26   CONTINUE
      IF(MORE)GOTO246
      IF(MLFO.OR.LO1.OR.SUMMER)RETURN
      WRITE(IW1,6092)
      DO27J=MLF1,MLFN
      J1=JOUT(J)
 0027 WRITE(IW1,6093)J1,NAMFAC(J1),LS(J)
      RETURN
 6081 FORMAT(1H0,23X,11(2X,2A4))
 6082 FORMAT(1H ,17X,6HFROM//,I4,A5,8(I5,A5))
 6091 FORMAT(13H TO FACILITY ,I2,A5,3H.. ,10I10)
 6092 FORMAT(54H0TOTAL VOLUMES RECEIVED BY ALL-YEAR DEADEND FACILITIES/)
 6093 FORMAT(1H ,10X,I2,A5,I15)
      END
      SUBROUTINEM2VEC(MTWO,NF)
      DIMENSIONMTWO(NF)
      MTWO(1)=1
      J=NF-1
      DO1I=1,J
 1    MTWO(I+1)=MTWO(I)+MTWO(I)
      RETURN
      END                                                               16220000
      SUBROUTINEIRANK(NUMSET,IORDER,NUMBER)                             16230000
      DIMENSIONNUMSET(NUMBER),IORDER(NUMBER)                            16240000
      LOGICALCHANGE                                                     16250000
      DO1003L=1,NUMBER                                                  16260000
 1003 IORDER(L)=L                                                       16270000
      IF(NUMBER.EQ.1)RETURN                                             16280000
      I=NUMBER-1                                                        16290000
 1004 CHANGE=.FALSE.                                                    16300000
      DO1005L=1,I                                                       16310000
      L1=L+1                                                            16320000
      J=IORDER(L)                                                       16330000
      J1=IORDER(L1)                                                     16340000
      IF(NUMSET(J).LE.NUMSET(J1))GOTO1005                               16350000
      IORDER(L)=J1                                                      16360000
      IORDER(L1)=J                                                      16370000
      CHANGE=.TRUE.                                                     16380000
 1005 CONTINUE                                                          16390000
      IF(CHANGE)GOTO1004                                                16400000
      RETURN                                                            16410000
      END                                                               16420000
      SUBROUTINEDECODE(JOUT,NFAC,ID,MTWO,NF)                            16430000
      DIMENSIONJOUT(NF),MTWO(NF)                                        16440000
      J=NF                                                              16450000
      K=NF                                                              16460000
      DO20I=1,NF                                                        16470000
      IF(MTWO(J).GT.ID)GOTO20                                           16480000
      JOUT(K)=J                                                         16490000
      K=K-1                                                             16500000
      ID=ID-MTWO(J)                                                     16510000
 0020 J=J-1                                                             16520000
      NFAC=NF-K                                                         16530000
      DO30I=1,NFAC                                                      16540000
 0030 JOUT(I)=JOUT(I+K)                                                 16550000
      RETURN                                                            16560000
      END                                                               16570000
      FUNCTIONNOLIM(I)                                                  16580000
      NOLIM=0                                                           16590000
      J=(10*IROUND(I))/9                                                16600000
 0010 NOLIM=NOLIM+J                                                     16610000
      IF(NOLIM.LE.I)GOTO10                                              16620000
      RETURN                                                            16630000
      END                                                               16640000
      FUNCTIONIROUND(N)                                                 16650000
      I=10                                                              16660000
 0010 IF(I.GT.N)GOTO00020                                               16670000
      I=I*10                                                            16680000
      GOTO00010                                                         16690000
 0020 IROUND=I/10                                                       16700000
      RETURN                                                            16710000
      END                                                               16720000
```

APPENDIX VII

SAMPLE PRINTOUT FROM ALL02

APPENDIX VII

SAMPLE PRINTOUT FROM ALL02

These are excerpts from the printout from one run containing three data cases, namely run no. 16 of the Niagara Study discussed in Chapter 7, section 2. The printout is fully explained in section 2.5 of that chapter and it is typical of all printout obtained from ALL02. We have indicated the end of one excerpt and the beginning of the next by wavy lines across the printout. The first data case is shown in its entirety.

With ALL02 as listed in Appendix VI, the printout has one difference from that illustrated here: tables of transport cost information (for example on the 2nd to 5th pages of this printout) are two-thirds as wide and 50% longer than shown here. For the Niagara Study we simply increased the field repetition factors in the appropriate format statements to taken advantage of the wide printout paper available to us.

```
BEGINNING ALLOC

            NIAGARA DATA SET NUMBER TWO  -  USING VRFD PLANTS ALL YEAR

NUMBER OF SOURCES  6

NUMBER OF FACILITIES

              SUMMER DEAD-END . . . . . . . . . . . .   8
              ALL-YEAR INTERMEDIATE . . . . . . . . .   0
              ALL-YEAR DEAD-END . . . . . . . . . . .  11
              WINTER STORAGE  . . . . . . . . . . . .   8

SOURCE NAMES USED ARE

            1  GMLN      GRIMSBY-LINCOLN                                  ////IN THIS RUN THE LOADING
            2  PWDH      PORT WELLER AND PORT DALHOUSIE, COMBINED           COSTS ARE HIGHER...
            3  NFLS      NIAGARA FALLS                                      ALSO THE VF SIZE LIMITS
            4  FERI      FORT ERIE                                          ARE RAISED WITH TIME////
            5  PCBN      PORT COLBORNE
            6  WLND      WELLAND

FACILITY NAMES USED ARE

            1  FFLS      LANDSPREAD AT FORT ERIE
            2  NFLS      LANDSPREAD AT NETHERBY
            3  PCLS      LANDSPREAD AT PORT COLBORNE
            4  PALS      LANDSPREAD AT POINT ALBINO
            5  CYLS      LANDSPREAD AT CYANAMID
            6  RSLS      LANDSPREAD AT ROSEDENE
            7  WFLS      LANDSPREAD AT WAINFLEET
            8  CSLS      LANDSPREAD AT CAISTORVILLE
            9  FFDL      DRYING LAGOON AT FORT ERIE             (OUTPUT TO FFLS)
           10  NFDL      DRYING LAGOON AT NETHERBY              (OUTPUT TO NFLS)
           11  PCDL      DRYING LAGOON AT PORT COLBORNE         (OUTPUT TO PCLS)
           12  PADL      DRYING LAGOON AT POINT ALBINO          (OUTPUT TO PALS)
           13  CYDL      DRYING LAGOON AT CYANAMID              (OUTPUT TO CYLS)
           14  RSDL      DRYING LAGOON AT ROSEDENE              (OUTPUT TO RSLS)
           15  WFDL      DRYING LAGOON AT WAINFLEET             (OUTPUT TO WFLS)
           16  CSDL      DRYING LAGOON AT CAISTORVILLE          (OUTPUT TO CSLS)
           17  PDVF      VACUUM FILTER AT PORT DALHOUSIE        (OUTPUT TO FFLS)
           18  NFVF      VACUUM FILTER AT NIAGARA FALLS         (OUTPUT TO CYLS)
           19  WDVF      VACUUM FILTER AT WELLAND               (OUTPUT TO PCLS)
           20  FFHT      HOLDING TANK AT FORT ERIE
           21  NFHT      HOLDING TANK AT NETHERBY
           22  PCHT      HOLDING TANK AT PORT COLBORNE
           23  PAHT      HOLDING TANK AT POINT ALBINO
           24  CYHT      HOLDING TANK AT CYANAMID
           25  RSHT      HOLDING TANK AT ROSEDENE
           26  WFHT      HOLDING TANK AT WAINFLEET
           27  CSHT      HOLDING TANK AT CAISTORVILLE

 TRAVELLING FACTOR    0.0

 EPS=     100000      MAXSOL=    20
```

```
CASE NUMBER  1

             DATA CASE FOR 1974

ANNUAL PRODUCTION AT SOURCES          1 GMLN     332000      2 PWDH    8414000      3 NFLS    2448000       4 FFRI      784000
                                      5 PCBN     894000      6 WLND     800000

FACILITY PARAMETERS               LIM           CONF           CONV            DAMF           DAMV             VRED
                     1 FELS     1550000            0     0.0                      0      0.0               0.0
                     2 NFLS    22222222            0     3.500E-03                0      1.500E-03         0.0
                     3 PCLS     2150000            0     0.0                      0      0.0               0.0
                     4 PALS    22222222            0     3.500E-03                0      1.500E-03         0.0
                     5 CYLS    22222222            0     3.500E-03                0      1.500E-03         0.0
                     6 RSLS    22222222            0     3.500E-03                0      1.500E-03         0.0
                     7 WFLS    22222222            0     3.500E-03                0      1.500E-03         0.0
                     8 CSLS    22222222            0     3.500E-03                0      1.500E-03         0.0
                     9 FEDL     2580000            0     5.222E-03                0      4.680E-06         2.600E-01
                    10 NEDL     9000000            0     1.300E-02                0      2.805E-03         2.600E-01
                    11 PCDL     3560000            0     5.222E-03                0      4.680E-06         2.600E-01
                    12 PADL     9000000            0     1.300E-02                0      2.805E-03         2.600E-01
                    13 CYDL     9000000            0     1.300E-02                0      2.805E-03         2.600E-01
                    14 RSDL     9000000            0     1.300E-02                0      2.805E-03         2.600E-01
                    15 WFDL     9000000            0     1.300E-02                0      2.805E-03         2.600E-01
                    16 CSDL     9000000            0     1.300E-02                0      2.805E-03         2.600E-01
                    17 PDVF     5900000         3000     0.0                  35000      1.032E-02         0.0
                    18 NFVF     2450000         3000     0.0                  35000      1.773E-02         0.0
                    19 WDVF     1800000         3000     0.0                  35000      2.614E-02         0.0
                    20 FEHT    22222222         3000     1.399E-03              200      7.400E-06         1.000E 00
                    21 NFHT    22222222         3000     2.304E-03              200      7.400E-06         1.000E 00
                    22 PCHT    22222222         3000     1.399E-03              200      7.400E-06         1.000E 00
                    23 PAHT    22222222         3000     2.304E-03              200      7.400E-06         1.000E 00
                    24 CYHT    22222222         3000     2.304E-03              200      7.400E-06         1.000E 00
                    25 RSHT    22222222         3000     2.304E-03              200      7.400E-06         1.000E 00
                    26 WFHT    22222222         3000     2.304E-03              200      7.400E-06         1.000E 00
                    27 CSHT    22222222         3000     2.304E-03              200      7.400E-06         1.000E 00

LICLF=1  WINTER=0.50000000

MODE OF DISTRIBUTION COST ARRAY CALCULATION IS IDST
HAULAGE FORMULAS . . . .
 1 COST PER UNIT VOLUME =  6.0000E-03 PLUS  6.0000E-03 TIMES TRIP LENGTH
 2 COST PER UNIT VOLUME =  0.0        PLUS  7.2000E-05 TIMES TRIP LENGTH
 3 COST PER UNIT VOLUME =  0.0        PLUS  1.5000E 00 TIMES TRIP LENGTH

                                              UNI TRANS  UNIT VARI                      UNI TRANS  UNIT VARI                      UNI TRANS  UNIT VARI
                                    DISTANCE  PORT COST  ABLE COST          DISTANCE    PORT COST  ABLE COST         DISTANCE    PORT COST  ABLE COST
USING HAULAGE FORMULA..          1                                  1                                         1
                                 1                                  1                                         1
TO FACILITY  1 FROM SOURCE      1.   2.1000     0.0186     0.0186  2.   1.4000      0.0144     0.0144  3.   0.9000      0.0114     0.0114
                                4.   0.2667     0.0076     0.0076  5.   1.3333      0.0140     0.0140  6.   1.3333      0.0140     0.0140
USING HAULAGE FORMULA..          1                                  1                                         1
                                 1                                  1                                         1
TO FACILITY  2 FROM SOURCE      1.   1.7500     0.0165     0.0215  2.   1.5000      0.0150     0.0200  3.   1.2000      0.0132     0.0182
                                4.   0.8667     0.0112     0.0162  5.   0.9333      0.0116     0.0166  6.   0.6667      0.0100     0.0150
USING HAULAGE FORMULA..          1                                  1                                         1
                                 1                                  1                                         1
TO FACILITY  3 FROM SOURCE      1.   1.9500     0.0177     0.0177  2.   1.7667      0.0166     0.0166  3.   1.6667      0.0160     0.0160
                                4.   1.7333     0.0164     0.0164  5.   0.4000      0.0084     0.0084  6.   0.5000      0.0090     0.0090
USING HAULAGE FORMULA..          1                                  1                                         1
```

```
                                 1                                                                 1
TO FACILITY  4 FROM SOURCE       1.  2.1000    0.0186    0.0236  2.  1.9667    0.0178    0.0228  3.  2.0000    0.0180    0.0230
                                 4.  1.4000    0.0144    0.0194  5.  0.6667    0.0100    0.0150  6.  1.2000    0.0132    0.0182
USING HAULAGE FORMULA..          1                               1                                 1
                                 1                               1                                 1
TO FACILITY  5 FROM SOURCE       1.  1.7000    0.0162    0.0212  2.  1.4333    0.0146    0.0196  3.  0.8000    0.0108    0.0158
                                 4.  1.4667    0.0148    0.0198  5.  1.2000    0.0132    0.0182  6.  0.5333    0.0092    0.0142
USING HAULAGE FORMULA..          1                               1                                 1
                                 .                               1                                 1
TO FACILITY  6 FROM SOURCE       1.  0.8000    0.0108    0.0158  2.  1.5000    0.0150    0.0200  3.  1.4667    0.0148    0.0198
                                 4.  1.9500    0.0177    0.0227  5.  1.5333    0.0152    0.0202  6.  1.1333    0.0128    0.0178
USING HAULAGE FORMULA..          1                               1                                 1
                                 1                               .                                 1
TO FACILITY  7 FROM SOURCE       1.  2.0000    0.0180    0.0230  2.  1.8000    0.0168    0.0218  3.  1.7333    0.0164    0.0214
                                 4.  1.9333    0.0176    0.0226  5.  0.5333    0.0092    0.0142  6.  0.9333    0.0116    0.0166
USING HAULAGE FORMULA..          1                               1                                 1
                                 1                               1                                 1
TO FACILITY  8 FROM SOURCE       1.  1.4667    0.0148    0.0198  2.  2.6333    0.0218    0.0268  3.  2.6000    0.0216    0.0266
                                 4.  2.8000    0.0228    0.0278  5.  2.6667    0.0220    0.0270  6.  2.2667    0.0196    0.0246
USING HAULAGE FORMULA..          1                               1                                 1
                                 1                               1                                 1
TO FACILITY  9 FROM SOURCE       1.  2.1000    0.0186    0.0238  2.  1.4000    0.0144    0.0196  3.  0.9000    0.0114    0.0165
                                 4.  0.2667    0.0076    0.0128  5.  1.3333    0.0140    0.0192  6.  1.3333    0.0140    0.0192
USING HAULAGE FORMULA..          1                               1                                 1
                                 .                               1                                 3
TO FACILITY 10 FROM SOURCE       1.  1.7500    0.0165    0.0323  2.  1.5000    0.0150    0.0308  3.  1.2000    0.0132    0.0290
                                 4.  0.8667    0.0112    0.0270  5.  0.9333    0.0116    0.0274  6.  0.8667    0.0112    0.0270
USING HAULAGE FORMULA..          1                               1                                 1
                                 1                               1                                 1
TO FACILITY 11 FROM SOURCE       1.  1.9500    0.0177    0.0229  2.  1.7667    0.0166    0.0218  3.  1.6667    0.0160    0.0212
                                 4.  1.7333    0.0164    0.0216  5.  0.4000    0.0084    0.0136  6.  0.5000    0.0090    0.0142
USING HAULAGE FORMULA..          1                               1                                 1
                                 1                               .                                 1
TO FACILITY 12 FROM SOURCE       1.  2.1000    0.0186    0.0344  2.  1.9667    0.0178    0.0336  3.  2.0000    0.0180    0.0338
                                 4.  1.4000    0.0144    0.0302  5.  0.6667    0.0100    0.0258  6.  1.2000    0.0132    0.0290
USING HAULAGE FORMULA..          1                               1                                 1
                                 1                               1                                 1
TO FACILITY 13 FROM SOURCE       1.  1.7000    0.0162    0.0320  2.  1.4333    0.0146    0.0304  3.  0.8000    0.0108    0.0266
                                 4.  1.4667    0.0148    0.0306  5.  1.2000    0.0132    0.0290  6.  0.5333    0.0092    0.0250
USING HAULAGE FORMULA..          1                               1                                 1
                                 1                               1                                 1
TO FACILITY 14 FROM SOURCE       1.  0.8000    0.0108    0.0266  2.  1.5000    0.0150    0.0308  3.  1.4667    0.0148    0.0306
                                 4.  1.9500    0.0177    0.0335  5.  1.5333    0.0152    0.0310  6.  1.1333    0.0128    0.0286
USING HAULAGE FORMULA..          1                               .                                 1
                                 1                               .                                 1
TO FACILITY 15 FROM SOURCE       1.  2.0000    0.0180    0.0338  2.  1.8000    0.0168    0.0326  3.  1.7333    0.0164    0.0322
                                 4.  1.9333    0.0176    0.0334  5.  0.5333    0.0092    0.0250  6.  0.9333    0.0116    0.0274
USING HAULAGE FORMULA..          1                               1                                 1
                                 1                               1                                 1
TO FACILITY 16 FROM SOURCE       1.  1.4667    0.0148    0.0306  2.  2.6333    0.0218    0.0376  3.  2.6000    0.0216    0.0374
                                 4.  2.8000    0.0228    0.0386  5.  2.6667    0.0220    0.0378  6.  2.2667    0.0196    0.0354
USING HAULAGE FORMULA..          1                               3                                 1
                                 1                               1                                 1
TO FACILITY 17 FROM SOURCE       1.  1.1333    0.0128    0.0231  2.  0.0030    0.0045    0.0148  3.  1.0000    0.0120    0.0223
                                 4.  1.7000    0.0162    0.0265  5.  1.6000    0.0156    0.0259  6.  1.2667    0.0136    0.0239
USING HAULAGE FORMULA..          1                               1                                 3
                                 1                               1                                 1
TO FACILITY 18 FROM SOURCE       1.  1.8667    0.0172    0.0349  2.  1.0667    0.0124    0.0301  3.  0.0       0.0       0.0177
                                 4.  1.2500    0.0135    0.0312  5.  1.6000    0.0156    0.0333  6.  1.0667    0.0124    0.0301
USING HAULAGE FORMULA..          1                               .                                 1
```

```
                                1                              1                              3
TO FACILITY 19 FROM SOURCE      1.  1.6500    0.0159   0.0420  2.  1.3333    0.0140   0.0401  3.  1.0667    0.0124   0.0385
USING HAULAGE FORMULA..         4.  1.4667    0.0148   0.0409  5.  0.6000    0.0096   0.0357  6.  0.0       0.0      0.0261
                                1                              1                              1
                                1                              1                              1
TO FACILITY 20 FROM SOURCE      1.  2.1000    0.0186   0.0200  2.  1.4000    0.0144   0.0158  3.  0.9000    0.0114   0.0128
USING HAULAGE FORMULA..         4.  0.2667    0.0076   0.0090  5.  1.3333    0.0140   0.0154  6.  1.3333    0.0140   0.0154
                                1                              1                              1
                                1                              1                              1
TO FACILITY 21 FROM SOURCE      1.  1.7500    0.0165   0.0188  2.  1.5000    0.0150   0.0173  3.  1.2000    0.0132   0.0155
USING HAULAGE FORMULA..         4.  0.8667    0.0112   0.0135  5.  0.9333    0.0116   0.0139  6.  0.6667    0.0100   0.0123
                                1                              1                              1
                                1                              1                              1
TO FACILITY 22 FROM SOURCE      1.  1.9500    0.0177   0.0191  2.  1.7667    0.0166   0.0180  3.  1.6667    0.0160   0.0174
USING HAULAGE FORMULA..         4.  1.7333    0.0164   0.0178  5.  0.4000    0.0084   0.0098  6.  0.5000    0.0090   0.0104
                                1                              1                              1
                                1                              1                              1
TO FACILITY 23 FROM SOURCE      1.  2.1000    0.0186   0.0209  2.  1.9667    0.0178   0.0201  3.  2.0000    0.0180   0.0203
USING HAULAGE FORMULA..         4.  1.4000    0.0144   0.0167  5.  0.6667    0.0100   0.0123  6.  1.2000    0.0132   0.0155
                                1                              1                              1
                                1                              1                              1
TO FACILITY 24 FROM SOURCE      1.  1.7000    0.0162   0.0185  2.  1.4333    0.0146   0.0169  3.  0.8000    0.0108   0.0131
USING HAULAGE FORMULA..         4.  1.4667    0.0148   0.0171  5.  1.2000    0.0132   0.0155  6.  0.5333    0.0092   0.0115
                                1                              1                              1
                                1                              1                              1
TO FACILITY 25 FROM SOURCE      1.  0.8000    0.0108   0.0131  2.  1.5000    0.0150   0.0173  3.  1.4667    0.0148   0.0171
USING HAULAGE FORMULA..         4.  1.9500    0.0177   0.0200  5.  1.5333    0.0152   0.0175  6.  1.1333    0.0128   0.0151
                                1                              1                              1
                                1                              1                              1
TO FACILITY 26 FROM SOURCE      1.  2.0000    0.0180   0.0203  2.  1.8000    0.0168   0.0191  3.  1.7333    0.0164   0.0187
USING HAULAGE FORMULA..         4.  1.9333    0.0176   0.0199  5.  0.5333    0.0092   0.0115  6.  0.9333    0.0116   0.0139
                                1                              1                              1
                                1                              1                              1
TO FACILITY 27 FROM SOURCE      1.  1.4667    0.0148   0.0171  2.  2.6333    0.0218   0.0241  3.  2.6000    0.0216   0.0239
USING HAULAGE FORMULA..         4.  2.8000    0.0228   0.0251  5.  2.6667    0.0220   0.0243  6.  2.2667    0.0196   0.0219
                                2
                                1                              1                              1
                                1                              1                              1
TO FACILITY  1 FROM FACILITY   20.  0.2500    0.0000   0.0000 21.  0.7333    0.0104   0.0104 22.  1.3333    0.0140   0.0140
                               23.  0.8000    0.0108   0.0108 24.  1.2000    0.0132   0.0132 25.  1.7500    0.0165   0.0165
USING HAULAGE FORMULA..        26.  1.5333    0.0152   0.0152 27.  2.4500    0.0207   0.0207
                                1                              2
                                1                              1                              1
                                1                              1                              1
TO FACILITY  2 FROM FACILITY   20.  0.7333    0.0104   0.0311 21.  0.2500    0.0000   0.0207 22.  1.2000    0.0132   0.0339
                               23.  0.7000    0.0102   0.0309 24.  0.8000    0.0108   0.0315 25.  1.6667    0.0160   0.0367
USING HAULAGE FORMULA..        26.  1.5333    0.0152   0.0359 27.  2.7333    0.0224   0.0431
                                1                              1
                                1                              1                              2
                                1                              1                              1
TO FACILITY  3 FROM FACILITY   20.  1.3333    0.0140   0.0140 21.  1.2000    0.0132   0.0132 22.  0.2500    0.0000   0.0000
                               23.  0.9333    0.0116   0.0116 24.  1.1000    0.0126   0.0126 25.  1.2667    0.0136   0.0136
USING HAULAGE FORMULA..        26.  0.5333    0.0092   0.0092 27.  2.0667    0.0184   0.0184
                                1                              1
                                2                              1                              1
                                1                              1                              1
TO FACILITY  4 FROM FACILITY   20.  0.8000    0.0108   0.0158 21.  0.7000    0.0102   0.0152 22.  0.9333    0.0116   0.0166
                               23.  0.2500    0.0000   0.0050 24.  1.0000    0.0120   0.0170 25.  1.9333    0.0176   0.0226
USING HAULAGE FORMULA..        26.  1.8000    0.0168   0.0218 27.  2.5667    0.0214   0.0264
                                1                                                             1
```

```
                                        1                                2                                1
                                        1                                1
TO FACILITY  5 FROM FACILITY 20.  1.2000      0.0132      0.0182 21.  0.8000      0.0108      0.0158 22.  1.1000      0.0126      0.0176
                             23.  1.0000      0.0120      0.0170 24.  0.2500      0.0000      0.0050 25.  1.4000      0.0144      0.0194
                             26.  1.4667      0.0148      0.0198 27.  2.0000      0.0180      0.0230
USING HAULAGE FORMULA..         1                                1                                1
                                1                                1                                2
                                1                                1
TO FACILITY  6 FROM FACILITY 20.  1.7500      0.0165      0.0215 21.  1.6667      0.0160      0.0210 22.  1.2667      0.0136      0.0186
                             23.  1.9333      0.0176      0.0226 24.  1.4000      0.0144      0.0194 25.  0.2500      0.0000      0.0050
                             26.  0.9333      0.0116      0.0166 27.  1.2667      0.0136      0.0186
USING HAULAGE FORMULA..         1                                1                                1
                                1                                1                                1
                                2                                2
TO FACILITY  7 FROM FACILITY 20.  1.5333      0.0152      0.0202 21.  1.5333      0.0152      0.0202 22.  0.5333      0.0092      0.0142
                             23.  1.8000      0.0168      0.0218 24.  1.4667      0.0148      0.0198 25.  0.9333      0.0116      0.0166
                             26.  0.2500      0.0000      0.0050 27.  1.6000      0.0156      0.0206
USING HAULAGE FORMULA..         1                                1                                1
                                1                                1                                1
                                1                                2
TO FACILITY  8 FROM FACILITY 20.  2.4500      0.0207      0.0257 21.  2.7333      0.0224      0.0274 22.  2.0667      0.0184      0.0234
                             23.  2.5667      0.0214      0.0264 24.  2.0000      0.0180      0.0230 25.  1.2667      0.0136      0.0186
                             26.  1.6000      0.0156      0.0206 27.  0.2500      0.0000      0.0050

FOR COMPUTATION THE DATA IS BEING MODIFIED AS FOLLOWS..

VARIABLE COSTS ARE MULTIPLIED BY     100000
SLUDGE QUANTITIES AND LIMITS ARE DIVIDED BY        100
FIXED COSTS ARE MULTIPLIED BY 1.0000000E 03
THE WINTER FACTOR IS CONVERTED TO THE RATIO OF THE TWO NUMBERS         50  OVER         100
THE WEIGHTING FACTOR THAT WAS READ IN, 0.0            ,
 YIELDS MULTIPLICATION OF VARIABLE ALL-YEAR FACILITY COSTS BY 100  OVER 100
 FOR PURPOSES OF COST COMPARISON IN THE WINTER SYSTEM.
FOR EASY READING ALL SOLUTIONS WILL BE PRINTED OUT IN TERMS OF THE ORIGINAL DATA.
```

```
ALL OF THE 134217727  POSSIBLE COMBINATIONS OF FACILITIES WILL BE CONSIDERED.
EVERY        300 TH. COMBINATION REACHING THE SURVEY WILL BE DONE WITH NETOUT FOR
DETAILED TREATMENT INCLUDING PRINTOUT OF BEST SLUDGE DISTRIBUTION PATTERNS AND COSTS.
DATA DUMP WILL OCCUR AT INTERVALS OF       1000

COST SURVEY BEGINNING WITH CURRENT MINIMUM TOTAL SYSTEM COST = 999999999
```

```
FACILITY  1FELS IS INCLUDED IN EVERY COMBINATION
FACILITY  2NELS IS INCLUDED IN EVERY COMBINATION
FACILITY  3PCLS IS INCLUDED IN EVERY COMBINATION
FACILITY  4PALS IS INCLUDED IN EVERY COMBINATION
FACILITY  5CYLS IS INCLUDED IN EVERY COMBINATION
FACILITY  6RSLS IS INCLUDED IN EVERY COMBINATION
FACILITY  7WFLS IS INCLUDED IN EVERY COMBINATION
FACILITY  8CSLS IS INCLUDED IN EVERY COMBINATION
FACILITY  9FEDL IS INCLUDED IN EVERY COMBINATION
FACILITY 10NEDL IS INCLUDED IN EVERY COMBINATION
FACILITY 11PCDL IS INCLUDED IN EVERY COMBINATION
FACILITY 12PADL IS INCLUDED IN EVERY COMBINATION
FACILITY 13CYDL IS INCLUDED IN EVERY COMBINATION
FACILITY 14RSDL IS INCLUDED IN EVERY COMBINATION
FACILITY 15WFDL IS INCLUDED IN EVERY COMBINATION
FACILITY 16CSDL IS INCLUDED IN EVERY COMBINATION

THE MAXIMUM NUMBER OF FACILITIES OF ONE KIND IN ANY COMBINATION IS
                 6 SUMMER DEADEND
                 0 ALL-YEAR INTERMEDIATE
                 6 ALL-YEAR DEADEND
                 6 WINTER STORAGE




////////// A FACILITY SUBSET IS BEING DONE WITH NETOUT. THIS IS THE        300  TH. SUBSET IN THE SURVEY.
FACILITY NAMES
                SUMMER DEAD-END . . . . . . . . . .  1 FELS  2 NFLS  3 PCLS  4 PALS  5 CYLS  6 RSLS  7 WFLS  8 CSLS
                ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 10 NEDL 11 PCDL 12 PADL 13 CYDL 14 RSDL  5 WFDL 16 CSDL 17 PDVF
                WINTER STORAGE  . . . . . . . . . . 20 FFHT 21 NEHT 25 RSHT

                                                                  TOTAL FIXED COST          47600

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                           SLUDGE DISTRIBUTION PATTERN


                               SOURCE      SOURCE      SOURCE      SOURCE      SOURCE
                     FROM//    1 GMLN      2 PWDH      3 NFLS      4 FFRI      5 PCBN
TO FACILITY  9 FEDL..               0           0           0           0           0
TO FACILITY 10 NEDL..               0           0           0           0           0
TO FACILITY 11 PCDL..               0           0           0           0      894000
TO FACILITY 12 PADL..               0           0           0           0           0
TO FACILITY 13 CYDL..               0           0           0           0           0
TO FACILITY 14 RSDL..               0           0           0           0           0
TO FACILITY 15 WFDL..               0           0           0           0           0
TO FACILITY 16 CSDL..               0           0           0           0           0
TO FACILITY 17 PDVF..               0     5900000           0           0           0
TO FACILITY 20 FFHT..               0     1257000     1224000       92000           0
TO FACILITY 21 NFHT..               0           0           0           0           0
TO FACILITY 25 RSHT..          166000           0           0           0           0
```

```
                                SOURCE      TOTAL
                       FROM//   6 WLND
TO FACILITY  9 FEDL..                0          0
TO FACILITY 10 NEDL..                0          0
TO FACILITY 11 PCDL..                0     894000
TO FACILITY 12 PADL..                0          0
TO FACILITY 13 CYDL..                0          0
TO FACILITY 14 RSDL..                0          0
TO FACILITY 15 WFDL..                0          0
TO FACILITY 16 CSDL..                0          0
TO FACILITY 17 PDVF..                0    5900000
TO FACILITY 20 FEHT..                0    2573000
TO FACILITY 21 NEHT..           400000     400000
TO FACILITY 25 RSHT..                0     166000

                                                          TOTAL VARIABLE COST            143105
                                                          SYSTEM COST TOTAL SO FAR          190705

SUMMER PORTION OF SYSTEM

                                  SLUDGE DISTRIBUTION PATTERN

                                SOURCE      SOURCE      SOURCE      SOURCE      SOURCE      STORAGE     STORAGE
                       FROM//   1 GMLN      2 PWDH      3 NFLS      4 FERI      6 WLND     20 FEHT     21 NEHT
TO FACILITY  1 FELS..                0           0           0           0           0     1550000           0
TO FACILITY  2 NELS..                0           0           0       92000           0           0           0
TO FACILITY  3 PCLS..                0     1257000           0           0      400000       93000      400000
TO FACILITY  4 PALS..                0           0           0           0           0      930000           0
TO FACILITY  5 CYLS..                0           0     1224000           0           0           0           0
TO FACILITY  6 RSLS..           166000           0           0           0           0           0           0
TO FACILITY  7 WFLS..                0           0           0           0           0           0           0
TO FACILITY  8 CSLS..                0           0           0           0           0           0           0

                                STORAGE     TOTAL
                       FROM//  25 RSHT
TO FACILITY  1 FELS..                0    1550000
TO FACILITY  2 NELS..                0      92000
TO FACILITY  3 PCLS..                0    2150000
TO FACILITY  4 PALS..                0     930000
TO FACILITY  5 CYLS..                0    1224000
TO FACILITY  6 RSLS..           166000     332000
TO FACILITY  7 WFLS..                0          0
TO FACILITY  8 CSLS..                0          0

                                                          TOTAL VARIABLE COST             70059
                                                                SYSTEM COST TOTAL           260764
```

```
///////// A FACILITY SUBSET IS BEING DONE WITH NETOUT. THIS IS THE        600  TH. SUBSET IN THE SURVEY.
FACILITY NAMES
               SUMMER DEAD-END . . . . . . . . . .  1 FFLS  2 NFLS  3 PCLS  4 PALS  5 CYLS  6 RSLS  7 WFLS  8 CSLS
               ALL-YEAR DEAD-END . . . . . . . . .  9 FFDL 10 NFDL 11 PCDL 12 PADL 13 CYDL 14 RSDL 15 WFDL 16 CSDL 17 PDVF 18 NFVF
               WINTER STORAGE  . . . . . . . . . . 20 FFHT 22 PCHT 26 WFHT

                                                                         TOTAL FIXED COST            85600

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                    SLUDGE DISTRIBUTION PATTERN


                                 SOURCE     SOURCE      SOURCE      SOURCE     SOURCE
                         FROM//  1 GMLN     2 PWDH      3 NFLS      4 FFRI     5 PCBN
TO FACILITY  9 FFDL..         0          0           0           0          0
TO FACILITY 10 NFDL..         0          0           0           0          0
TO FACILITY 11 PCDL..         0          0           0           0          0
TO FACILITY 12 PADL..         0          0           0           0          0
TO FACILITY 13 CYDL..         0          0           0           0          0
TO FACILITY 14 RSDL..         0          0           0           0          0
TO FACILITY 15 WFDL..         0          0           0           0          0
TO FACILITY 16 CSDL..         0          0           0           0          0
TO FACILITY 17 PDVF..         0    5900000           0           0          0
TO FACILITY 18 NFVF..         0          0           0           0          0
TO FACILITY 20 FFHT..         0    1257000     1224000       92000          0
TO FACILITY 22 PCHT..    166000          0           0           0     447000
TO FACILITY 26 WFHT..         0          0           0           0          0

                                 SOURCE      TOTAL
                         FROM//  6 WLND
TO FACILITY  9 FFDL..         0          0
TO FACILITY 10 NFDL..         0          0
TO FACILITY 11 PCDL..         0          0
TO FACILITY 12 PADL..         0          0
TO FACILITY 13 CYDL..         0          0
TO FACILITY 14 RSDL..         0          0
TO FACILITY 15 WFDL..         0          0
TO FACILITY 16 CSDL..         0          0
TO FACILITY 17 PDVF..         0    5900000
TO FACILITY 18 NFVF..         0          0
TO FACILITY 20 FFHT..         0    2573000
TO FACILITY 22 PCHT..    400000    1013000
TO FACILITY 26 WFHT..         0          0

                                                                 TOTAL VARIABLE COST          135541
                                                                 SYSTEM COST TOTAL SO FAR         221141
```

```
SUMMER PORTION OF SYSTEM

                                    SLUDGE DISTRIBUTION PATTERN

                            SOURCE      SOURCE      SOURCE      SOURCE      SOURCE      SOURCE     STORAGE
                  FROM//    1 GMLN      2 PWDH      3 NFLS      4 FFRI      5 PCBN      6 WLND     20 FEHT
TO FACILITY  1 FFLS..            0           0           0           0           0           0    1550000
TO FACILITY  2 NFLS..            0           0           0       92000           0           0          0
TO FACILITY  3 PCLS..            0      290000           0           0      447000      400000          0
TO FACILITY  4 PALS..            0           0           0           0           0           0    1023000
TO FACILITY  5 CYLS..            0      967000     1224000           0           0           0          0
TO FACILITY  6 RSLS..       166000           0           0           0           0           0          0
TO FACILITY  7 WFLS..            0           0           0           0           0           0          0
TO FACILITY  8 CSLS..            0           0           0           0           0           0          0

                           STORAGE       TOTAL
                  FROM//   22 PCHT
TO FACILITY  1 FFLS..            0     1550000
TO FACILITY  2 NFLS..            0       92000
TO FACILITY  3 PCLS..      1013000     2150000
TO FACILITY  4 PALS..            0     1023000
TO FACILITY  5 CYLS..            0     2191000
TO FACILITY  6 RSLS..            0      166000
TO FACILITY  7 WFLS..            0           0
TO FACILITY  8 CSLS..            0           0

                                                              TOTAL VARIABLE COST           70789
                                                                     SYSTEM COST TOTAL          291930
```

```
///////// A FACILITY SUBSET IS BEING DONE WITH NETOUT. THIS IS THE        900  TH. SUBSET IN THE SURVEY.
FACILITY NAMES
                    SUMMER DEAD-END . . . . . . . . . .  1 FFLS  2 NFLS  3 PCLS  4 PALS  5 CYLS  6 RSLS  7 WFLS  8 CSLS
                    ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 10 NEDL 11 PCDL 12 PADL 13 CYDL 14 RSDL 15 WFDL 16 CSDL 19 WDVF
                    WINTER STORAGE  . . . . . . . . . . 20 FEHT 21 NFHT 22 PCHT 24 CYHT

                                                                     TOTAL FIXED COST           50800
```

```
WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                     SLUDGE DISTRIBUTION PATTERN

                                 SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                       FROM//   1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN
TO FACILITY  9 FFDL..          0          0          0          0          0
TO FACILITY 10 NFDL..          0          0          0          0          0
TO FACILITY 11 PCDL..          0          0          0          0          0
TO FACILITY 12 PADL..          0          0          0          0          0
TO FACILITY 13 CYDL..          0          0          0          0          0
TO FACILITY 14 RSDL..          0          0          0          0          0
TO FACILITY 15 WFDL..          0          0          0          0          0
TO FACILITY 16 CSDL..          0          0          0          0          0
TO FACILITY 19 WCVF..          0          0          0          0          0
TO FACILITY 20 FFHT..          0    4207000    1224000      92000          0
TO FACILITY 21 NFHT..          0          0          0          0          0
TO FACILITY 22 PCHT..          0          0          0          0     447000
TO FACILITY 24 CYHT..     166000          0          0          0          0

                                 SOURCE      TOTAL
                       FROM//   6 WLND
TO FACILITY  9 FFDL..          0          0
TO FACILITY 10 NFDL..          0          0
TO FACILITY 11 PCDL..          0          0
TO FACILITY 12 PADL..          0          0
TO FACILITY 13 CYDL..          0          0
TO FACILITY 14 RSDL..          0          0
TO FACILITY 15 WFDL..          0          0
TO FACILITY 16 CSDL..          0          0
TO FACILITY 19 WCVF..          0          0
TO FACILITY 20 FFHT..          0    5523000
TO FACILITY 21 NFHT..          0          0
TO FACILITY 22 PCHT..     400000     847000
TO FACILITY 24 CYHT..          0     166000

                                                            TOTAL VARIABLE COST               94643
                                                            SYSTEM COST TOTAL SO FAR             145443

SUMMER PORTION OF SYSTEM

                                     SLUDGE DISTRIBUTION PATTERN

                                 SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     STORAGE    STORAGE
                       FROM//   1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN     6 WLND    20 FFHT    22 PCHT
TO FACILITY  1 FFLS..          0          0          0          0          0          0    1550000          0
TO FACILITY  2 NFLS..          0          0          0      92000          0          0          0          0
TO FACILITY  3 PCLS..          0     456000          0          0     447000     400000          0     847000
TO FACILITY  4 PALS..          0          0          0          0          0          0    3973000          0
TO FACILITY  5 CYLS..          0    3751000    1224000          0          0          0          0          0
TO FACILITY  6 RSLS..     166000          0          0          0          0          0          0          0
TO FACILITY  7 WFLS..          0          0          0          0          0          0          0          0
TO FACILITY  8 CSLS..          0          0          0          0          0          0          0          0
```

```
                                STORAGE     TOTAL
                       FROM//  24 CYHT
TO FACILITY  1 FELS..        0   1550000
TO FACILITY  2 NELS..        0     92000
TO FACILITY  3 PCLS..        0   2150000
TO FACILITY  4 PALS..        0   3973000
TO FACILITY  5 CYLS..   166000   5141000
TO FACILITY  6 RSLS..        0    166000
TO FACILITY  7 WFLS..        0         0
TO FACILITY  8 CSLS..        0         0

                                                       TOTAL VARIABLE COST          175551
                                                             SYSTEM COST TOTAL          320994

***** DATA DUMP COMPLETED AT FACSET=       1000   *****
```

```
///////// A FACILITY SUBSET IS BEING DONE WITH NETOUT. THIS IS THE       1200  TH. SUBSET IN THE SURVEY.
FACILITY NAMES
          SUMMER DEAD-END . . . . . . . . . .  1 FELS  2 NFLS  3 PCLS  4 PALS  5 CYLS  6 RSLS  7 WFLS  8 CSLS
          ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 10 NEDL 11 PCDL 12 PADL 13 CYDL 14 RSDL 15 WFDL 16 CSDL 17 PDVF 19 WDVF
          WINTER STORAGE  . . . . . . . . . . 21 NEHT 23 PAHT 25 RSHT 27 CSHT

                                                            TOTAL FIXED COST          88800

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                SLUDGE DISTRIBUTION PATTERN


                                SOURCE      SOURCE      SOURCE      SOURCE      SOURCE
                       FROM//   1 GMLN      2 PWDH      3 NFLS      4 FERI      5 PCBN
TO FACILITY  9 FEDL..        0           0           0      184000           0
TO FACILITY 10 NEDL..        0           0           0           0           0
TO FACILITY 11 PCDL..        0           0           0           0           0
TO FACILITY 12 PADL..        0           0           0           0           0
TO FACILITY 13 CYDL..        0           0           0           0           0
TO FACILITY 14 RSDL..        0           0           0           0           0
TO FACILITY 15 WFDL..        0           0           0           0           0
TO FACILITY 16 CSDL..        0           0           0           0           0
TO FACILITY 17 PDVF..        0     5900000           0           0           0
TO FACILITY 19 WDVF..        0           0           0           0           0
TO FACILITY 21 NEHT..        0     1257000     1224000           0           0
TO FACILITY 23 PAHT..        0           0           0           0      447000
TO FACILITY 25 RSHT..   166000           0           0           0           0
TO FACILITY 27 CSHT..        0           0           0           0           0
```

```
                              SOURCE      TOTAL
                      FROM//  6 WLND
TO FACILITY  9 FEDL..              0     184000
TO FACILITY 10 NEDL..              0          0
TO FACILITY 11 PCDL..              0          0
TO FACILITY 12 PADL..              0          0
TO FACILITY 13 CYDL..              0          0
TO FACILITY 14 RSDL..              0          0
TO FACILITY 15 WEDL..              0          0
TO FACILITY 16 CSDL..              0          0
TO FACILITY 17 PDVF..              0    5900000
TO FACILITY 19 WDVF..              0          0
TO FACILITY 21 NEHT..         400000    2881000
TO FACILITY 23 PAHT..              0     447000
TO FACILITY 25 RSHT..              0     166000
TO FACILITY 27 CSHT..              0          0

                                                         TOTAL VARIABLE COST               143144
                                                         SYSTEM COST TOTAL SO FAR              231944

SUMMER PORTION OF SYSTEM

                                   SLUDGE DISTRIBUTION PATTERN

                              SOURCE      SOURCE      SOURCE      SOURCE      SOURCE      STORAGE     STORAGE
                      FROM//  1 GMLN      2 PWDH      3 NFLS      5 PCBN      6 WLND      21 NEHT     23 PAHT
TO FACILITY  1 FELS..              0           0           0           0           0     1550000           0
TO FACILITY  2 NELS..              0           0           0           0           0           0           0
TO FACILITY  3 PCLS..              0     1257000           0      447000      400000       46000           0
TO FACILITY  4 PALS..              0           0           0           0           0     1285000      447000
TO FACILITY  5 CYLS..              0           0     1224000           0           0           0           0
TO FACILITY  6 RSLS..         166000           0           0           0           0           0           0
TO FACILITY  7 WELS..              0           0           0           0           0           0           0
TO FACILITY  8 CSLS..              0           0           0           0           0           0           0

                              STORAGE     TOTAL
                      FROM//  25 RSHT
TO FACILITY  1 FELS..              0    1550000
TO FACILITY  2 NELS..              0          0
TO FACILITY  3 PCLS..              0    2150000
TO FACILITY  4 PALS..              0    1732000
TO FACILITY  5 CYLS..              0    1224000
TO FACILITY  6 RSLS..         166000     332000
TO FACILITY  7 WELS..              0          0
TO FACILITY  8 CSLS..              0          0

                                                         TOTAL VARIABLE COST                89519
                                                               SYSTEM COST TOTAL               321464
```

```
///////// A FACILITY SUBSET IS BEING DONE WITH NETOUT. THIS IS THE       1500  TH. SUBSET IN THE SURVEY.
FACILITY NAMES
                 SUMMER DEAD-END . . . . . . . . . .  1 FELS  2 NFLS  3 PCLS  4 PALS  5 CYLS  6 RSLS  7 WFLS  8 CSLS
                 ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 10 NEDL 11 PCDL 12 PADL 13 CYDL 14 RSDL 15 WFDL 16 CSDL 17 PDVF 18
                 ALL-YEAR DEAD-END . . . . . . . . . 19 WDVF
                 WINTER STORAGE  . . . . . . . . . . 20 FEHT 21 NEHT 25 RSHT 27 CSHT

                                                              TOTAL FIXED COST          126800

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                SLUDGE DISTRIBUTION PATTERN

                                SOURCE      SOURCE      SOURCE      SOURCE      SOURCE
                         FROM//  1 GMLN      2 PWDH      3 NFLS      4 FERI      5 PCBN
TO FACILITY  9 FEDL..            0           0           0           0           0
TO FACILITY 10 NEDL..            0           0           0           0           0
TO FACILITY 11 PCDL..            0           0           0           0      894000
TO FACILITY 12 PADL..            0           0           0           0           0
TO FACILITY 13 CYDL..            0           0           0           0           0
TO FACILITY 14 RSDL..            0           0           0           0           0
TO FACILITY 15 WFDL..            0           0           0           0           0
TO FACILITY 16 CSDL..            0           0           0           0           0
TO FACILITY 17 PDVF..            0     5900000           0           0           0
TO FACILITY 18 NEVF..            0           0           0           0           0
TO FACILITY 19 WDVF..            0           0           0           0           0
TO FACILITY 20 FEHT..            0     1257000     1224000       92000           0
TO FACILITY 21 NEHT..            0           0           0           0           0
TO FACILITY 25 RSHT..       166000           0           0           0           0
TO FACILITY 27 CSHT..            0           0           0           0           0

                                SOURCE       TOTAL
                         FROM//  6 WLND
TO FACILITY  9 FEDL..            0           0
TO FACILITY 10 NEDL..            0           0
TO FACILITY 11 PCDL..            0      894000
TO FACILITY 12 PADL..            0           0
TO FACILITY 13 CYDL..            0           0
TO FACILITY 14 RSDL..            0           0
TO FACILITY 15 WFDL..            0           0
TO FACILITY 16 CSDL..            0           0
TO FACILITY 17 PDVF..            0     5900000
TO FACILITY 18 NEVF..            0           0
TO FACILITY 19 WDVF..            0           0
TO FACILITY 20 FEHT..            0     2573000
TO FACILITY 21 NEHT..       400000      400000
TO FACILITY 25 RSHT..            0      166000
TO FACILITY 27 CSHT..            0           0

                                                      TOTAL VARIABLE COST           143105
                                                      SYSTEM COST TOTAL SO FAR         269905
```

```
SUMMER PORTION OF SYSTEM

                                       SLUDGE DISTRIBUTION PATTERN

                               SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     STORAGE    STORAGE
                     FROM//    1 GMLN     2 PWDH     3 NFLS     4 FERI     5 WLND    20 FEHT    21 NEHT
TO FACILITY  1 FFLS..               0          0          0          0          0    1550000          0
TO FACILITY  2 NELS..               0          0          0      92000          0          0          0
TO FACILITY  3 PCLS..               0    1257000          0          0     400000      93000     400000
TO FACILITY  4 PALS..               0          0          0          0          0     930000          0
TO FACILITY  5 CYLS..               0          0    1224000          0          0          0          0
TO FACILITY  6 RSLS..          166000          0          0          0          0          0          0
TO FACILITY  7 WFLS..               0          0          0          0          0          0          0
TO FACILITY  8 CSLS..               0          0          0          0          0          0          0

                               STORAGE     TOTAL
                     FROM//    25 RSHT
TO FACILITY  1 FFLS..               0    1550000
TO FACILITY  2 NELS..               0      92000
TO FACILITY  3 PCLS..               0    2150000
TO FACILITY  4 PALS..               0     930000
TO FACILITY  5 CYLS..               0    1224000
TO FACILITY  6 RSLS..          166000     332000
TO FACILITY  7 WFLS..               0          0
TO FACILITY  8 CSLS..               0          0

                                                               TOTAL VARIABLE COST            70059
                                                                      SYSTEM COST TOTAL          339964




////////// A FACILITY SUBSET IS BEING DONE WITH NETCUT. THIS IS THE       1800  TH. SUBSET IN THE SURVEY.
FACILITY NAMES
                    SUMMER DEAD-END . . . . . . . . . .  1 FFLS  2 NELS  3 PCLS  4 PALS  5 CYLS  6 RSLS  7 WFLS  8 CSLS
                    ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 10 NEDL 11 PCDL 12 PADL 13 CYDL 14 RSDL 15 WFDL 16 CSDL 19 WCVF
                    WINTER STORAGE  . . . . . . . . . . 20 FEHT 22 PCHT 24 CYHT 25 RSHT 26 WFHT 27 CSHT

                                                                      TOTAL FIXED COST           57200
```

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WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                SLUDGE DISTRIBUTION PATTERN

                             SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                  FROM//     1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN
TO FACILITY  9 FEDL..             0          0          0          0          0
TO FACILITY 10 NEDL..             0          0          0          0          0
TO FACILITY 11 PCDL..             0          0          0          0          0
TO FACILITY 12 PADL..             0          0          0          0          0
TO FACILITY 13 CYDL..             0          0          0          0          0
TO FACILITY 14 RSDL..             0          0          0          0          0
TO FACILITY 15 WFDL..             0          0          0          0          0
TO FACILITY 16 CSDL..             0          0          0          0          0
TO FACILITY 19 WDVF..             0          0          0          0          0
TO FACILITY 20 FEHT..             0    4207000    1224000      92000          0
TO FACILITY 22 PCHT..             0          0          0          0     447000
TO FACILITY 24 CYHT..             0          0          0          0          0
TO FACILITY 25 RSHT..        166000          0          0          0          0
TO FACILITY 26 WFHT..             0          0          0          0          0
TO FACILITY 27 CSHT..             0          0          0          0          0

                             SOURCE      TOTAL
                  FROM//     6 WLND
TO FACILITY  9 FEDL..             0          0
TO FACILITY 10 NEDL..             0          0
TO FACILITY 11 PCDL..             0          0
TO FACILITY 12 PADL..             0          0
TO FACILITY 13 CYDL..             0          0
TO FACILITY 14 RSDL..             0          0
TO FACILITY 15 WFDL..             0          0
TO FACILITY 16 CSDL..             0          0
TO FACILITY 19 WDVF..             0          0
TO FACILITY 20 FEHT..             0    5523000
TO FACILITY 22 PCHT..        400000     847000
TO FACILITY 24 CYHT..             0          0
TO FACILITY 25 RSHT..             0     166000
TO FACILITY 26 WFHT..             0          0
TO FACILITY 27 CSHT..             0          0

                                                           TOTAL VARIABLE COST                93746
                                                           SYSTEM COST TOTAL SO FAR               150946

SUMMER PORTION OF SYSTEM

                                SLUDGE DISTRIBUTION PATTERN

                             SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     STORAGE    STORAGE
                  FROM//     1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN     6 WLND     20 FEHT    22 PCHT
TO FACILITY  1 FFLS..             0          0          0          0          0          0    1550000          0
TO FACILITY  2 NFLS..             0          0          0      92000          0          0          0          0
TO FACILITY  3 PCLS..             0     456000          0          0     447000     400000          0     847000
TO FACILITY  4 PALS..             0          0          0          0          0          0    3973000          0
TO FACILITY  5 CYLS..             0    3751000    1224000          0          0          0          0          0
TO FACILITY  6 RSLS..        166000          0          0          0          0          0          0          0
TO FACILITY  7 WFLS..             0          0          0          0          0          0          0          0
TO FACILITY  8 CSLS..             0          0          0          0          0          0          0          0
```

```
                                    STORAGE     TOTAL
                         FROM//   25 RSHT
TO FACILITY  1 FFLS..           0    1550000
TO FACILITY  2 NFLS..           0      92000
TO FACILITY  3 PCLS..           0    2150000
TO FACILITY  4 PALS..           0    3973000
TO FACILITY  5 CYLS..           0    4975000
TO FACILITY  6 RSLS..      166000     332000
TO FACILITY  7 WFLS..           0          0
TO FACILITY  8 CSLS..           0          0

                                                          TOTAL VARIABLE COST          175551
                                                                SYSTEM COST TOTAL          326497
```

```
THE SURVEY IS FINISHED.        20 SOLUTIONS HAVE BEEN RETAINED, WITH TOTAL COSTS FROM          237424  TO 243857 .
THERE WERE SOME SOLUTIONS FROM          243857  TO          337424 ,
BUT IT WAS SPECIFIED NOT TO RETAIN MORE THAN          20  SOLUTIONS.
```

```
FACILITY COMBINATION RANK     1            TOTAL COST          237424
               SUMMER DEAD-END . . . . . . . . . . 1 FFLS  3 PCLS  5 CYLS  6 RSLS
               ALL-YEAR DEAD-END . . . . . . . . . 9 FEDL 11 PCDL
               WINTER STORAGE  . . . . . . . . . .24 CYHT

                                                        TOTAL FIXED COST           3200

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN

                            SOURCE      SOURCE      SOURCE      SOURCE      SOURCE
                    FROM//  1 GMLN      2 PWDH      3 NFLS      4 FERI      5 PCBN
TO FACILITY  9 FEDL..            0           0           0      184000           0
TO FACILITY 11 PCDL..            0           0           0           0      894000
TO FACILITY 24 CYHT..       166000     4207000     1224000           0           0

                            SOURCE       TOTAL
                    FROM//  6 WLND
TO FACILITY  9 FEDL..            0      184000
TO FACILITY 11 PCDL..            0      894000
TO FACILITY 24 CYHT..       400000     5997000

                                                   TOTAL VARIABLE COST          109410
                                                   SYSTEM COST TOTAL SO FAR         112610

SUMMER PORTION OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN

                            SOURCE      SOURCE      SOURCE      SOURCE     STORAGE      TOTAL
                    FROM//  1 GMLN      2 PWDH      3 NFLS      6 WLND     24 CYHT
TO FACILITY  1 FFLS..            0     1550000           0           0           0     550000
TO FACILITY  3 PCLS..            0     1750000           0      400000           0    2150000
TO FACILITY  5 CYLS..            0      907000     1224000           0     5997000    8128000
TO FACILITY  6 RSLS..       166000           0           0           0           0     166000

                                                   TOTAL VARIABLE COST          124814
                                                        SYSTEM COST TOTAL           237424
```

```
FACILITY COMBINATION RANK    2          TOTAL COST         237483
               SUMMER DEAD-END . . . . . . . . . .  1 FELS  3 PCLS  5 CYLS  6 RSLS
               ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 11 PCDL
               WINTER STORAGE  . . . . . . . . . . 25 RSHT

                                                                TOTAL FIXED COST              3200

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN

                          SOURCE    SOURCE    SOURCE    SOURCE    SOURCE
                 FROM//   1 GMLN    2 PWDH    3 NFLS    4 FFRI    5 PCBN
TO FACILITY  9 FEDL..          0         0   2396000    184000         0
TO FACILITY 11 PCDL..          0         0         0         0    894000
TO FACILITY 25 RSHT..     166000   4207000     26000         0         0

                          SOURCE     TOTAL
                 FROM//   6 WLND
TO FACILITY  9 FEDL..          0   2580000
TO FACILITY 11 PCDL..     800000   1694000
TO FACILITY 25 RSHT..          0   4399000

                                                        TOTAL VARIABLE COST          141220
                                                        SYSTEM COST TOTAL SO FAR          144420

SUMMER PORTION OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN

                          SOURCE    SOURCE    SOURCE    STORAGE     TOTAL
                 FROM//   1 GMLN    2 PWDH    3 NFLS    25 RSHT
TO FACILITY  1 FELS..          0   1550000         0          0   1550000
TO FACILITY  3 PCLS..          0   2150000         0          0   2150000
TO FACILITY  5 CYLS..          0    507000     26000          0    533000
TO FACILITY  6 RSLS..     166000         0         0    4399000   4565000

                                                        TOTAL VARIABLE COST          93064
                                                              SYSTEM COST TOTAL           237483
```

```
FACILITY COMBINATION RANK     3            TOTAL COST          238029
                SUMMER DEAD-END . . . . . . . . . .  1 FFLS  3 PCLS  5 CYLS  6 RSLS
                ALL-YEAR DEAD-END . . . . . . . . .  9 FFDL
                WINTER STORAGE  . . . . . . . . . . 22 PCHT 24 CYHT

                                                                 TOTAL FIXED COST            6400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                               SLUDGE DISTRIBUTION PATTERN

                               SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                      FROM//   1 GMLN     2 PWDH     3 NFLS     4 FFRI     5 PCBN
TO FACILITY  9 FFDL..               0          0          0     184000          0
TO FACILITY 22 PCHT..               0          0          0          0     447000
TO FACILITY 24 CYHT..          166000    4207000    1224000          0          0

                               SOURCE      TOTAL
                      FROM//   6 WLND
TO FACILITY  9 FFDL..               0     184000
TO FACILITY 22 PCHT..          400000     847000
TO FACILITY 24 CYHT..               0    5597000

                                                           TOTAL VARIABLE COST          101169
                                                           SYSTEM COST TOTAL SO FAR        107569

SUMMER PORTION OF SYSTEM

                               SLUDGE DISTRIBUTION PATTERN

                               SOURCE     SOURCE     SOURCE     SOURCE     SOURCE    STORAGE    STORAGE      TOTAL
                      FROM//   1 GMLN     2 PWDH     3 NFLS     5 PCBN     6 WLND    22 PCHT    24 CYHT
TO FACILITY  1 FFLS..               0    1550000          0          0          0          0          0    1550000
TO FACILITY  3 PCLS..               0     456000          0     447000     400000     847000          0    2150000
TO FACILITY  5 CYLS..               0    2201000    1224000          0          0          0    5597000    9022000
TO FACILITY  6 RSLS..          166000          0          0          0          0          0          0     166000

                                                           TOTAL VARIABLE COST          130460
                                                                SYSTEM COST TOTAL          238029
```

```
FACILITY COMBINATION RANK     4           TOTAL COST          238117
              SUMMER DEAD-END . . . . . . . . . . 1 FELS  3 PCLS  5 CYLS  6 RSLS
              ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL
              WINTER STORAGE  . . . . . . . . . . 22 PCHT 25 RSHT

                                                          TOTAL FIXED COST            6400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                     SLUDGE DISTRIBUTION PATTERN

                              SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                     FROM//   1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN
TO FACILITY  9 FEDL..              0          0    2396000     184000          0
TO FACILITY 22 PCHT..              0          0          0          0     447000
TO FACILITY 25 RSHT..         166000    4207000      26000          0          0

                              SOURCE      TOTAL
                     FROM//   6 WLND
TO FACILITY  9 FEDL..              0    2580000
TO FACILITY 22 PCHT..         400000     847000
TO FACILITY 25 RSHT..              0    4399000

                                                       TOTAL VARIABLE COST         126200
                                                       SYSTEM COST TOTAL SO FAR       132600

SUMMER PORTION OF SYSTEM

                     SLUDGE DISTRIBUTION PATTERN

                              SOURCE     SOURCE     SOURCE     SOURCE     SOURCE    STORAGE    STORAGE      TOTAL
                     FROM//   1 GMLN     2 PWDH     3 NFLS     5 PCBN     6 WLND    22 PCHT    25 RSHT
TO FACILITY  1 FELS..              0    1550000          0          0          0          0          0    1550000
TO FACILITY  3 PCLS..              0     456000          0     447000     400000     847000          0    2150000
TO FACILITY  5 CYLS..              0    2201000      26000          0          0          0          0    2227000
TO FACILITY  6 RSLS..         166000          0          0          0          0          0    4399000    4565000

                                                       TOTAL VARIABLE COST         105518
                                                            SYSTEM COST TOTAL         238117
```

```
FACILITY COMBINATION RANK     5            TOTAL COST          239727
               SUMMER DEAD-END . . . . . . . . . .  1 FELS  3 PCLS  5 CYLS  6 RSLS
               ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 11 PCDL
               WINTER STORAGE  . . . . . . . . . . 24 CYHT 25 RSHT

                                                                 TOTAL FIXED COST            6400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                           SLUDGE DISTRIBUTION PATTERN

                             SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                   FROM//    1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN
TO FACILITY  9 FEDL..             0          0          0     164000          0
TO FACILITY 11 PCDL..             0          0          0          0     894000
TO FACILITY 24 CYHT..             0    4207000    1224000          0          0
TO FACILITY 25 RSHT..        166000          0          0          0          0

                             SOURCE      TOTAL
                   FROM//    6 WLND
TO FACILITY  9 FEDL..             0     184000
TO FACILITY 11 PCDL..             0     894000
TO FACILITY 24 CYHT..        400000    5831000
TO FACILITY 25 RSHT..             0     166000

                                                      TOTAL VARIABLE COST          108513
                                                      SYSTEM COST TOTAL SO FAR        114913

SUMMER PORTION OF SYSTEM

                           SLUDGE DISTRIBUTION PATTERN

                             SOURCE     SOURCE     SOURCE     SOURCE     STORAGE    STORAGE      TOTAL
                   FROM//    1 GMLN     2 PWDH     3 NFLS     6 WLND     24 CYHT    25 RSHT
TO FACILITY  1 FELS..             0    1550000          0          0          0          0    1550000
TO FACILITY  3 PCLS..             0    1750000          0     400000          0          0    2150000
TO FACILITY  5 CYLS..             0     907000    1224000          0    5831000          0    7962000
TO FACILITY  6 RSLS..        166000          0          0          0          0     166000     332000

                                                      TOTAL VARIABLE COST          124814
                                                             SYSTEM COST TOTAL        239727
```

```
FACILITY COMBINATION RANK    6          TOTAL COST            240333
               SUMMER DEAD-END . . . . . . . . . .  1 FELS  3 PCLS  5 CYLS  6 RSLS
               ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL
               WINTER STORAGE  . . . . . . . . . . 22 PCHT 24 CYHT 25 RSHT

                                                                TOTAL FIXED COST              9600

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                   SLUDGE DISTRIBUTION PATTERN

                          SOURCE    SOURCE    SOURCE    SOURCE    SOURCE
                FROM//    1 GMLN    2 PWDH    3 NFLS    4 FERI    5 PCBN
TO FACILITY  9 FEDL..          0         0         0    184000         0
TO FACILITY 22 PCHT..          0         0         0         0    447000
TO FACILITY 24 CYHT..          0   4207000   1224000         0         0
TO FACILITY 25 RSHT..     166000         0         0         0         0

                          SOURCE     TOTAL
                FROM//    6 WLND
TO FACILITY  9 FEDL..          0    184000
TO FACILITY 22 PCHT..     400000    847000
TO FACILITY 24 CYHT..          0   5431000
TO FACILITY 25 RSHT..          0    166000

                                                        TOTAL VARIABLE COST          100273
                                                        SYSTEM COST TOTAL SO FAR          109873

SUMMER PORTION OF SYSTEM

                                   SLUDGE DISTRIBUTION PATTERN

                          SOURCE    SOURCE    SOURCE    SOURCE    SOURCE   STORAGE   STORAGE
                FROM//    1 GMLN    2 PWDH    3 NFLS    5 PCBN    6 WLND   22 PCHT   24 CYHT
TO FACILITY  1 FELS..          0   1550000         0         0         0         0         0
TO FACILITY  3 PCLS..          0    456000         0    447000    400000    847000         0
TO FACILITY  5 CYLS..          0   2201000   1224000         0         0         0   5431000
TO FACILITY  6 RSLS..     166000         0         0         0         0         0         0

                         STORAGE     TOTAL
                FROM//   25 RSHT
TO FACILITY  1 FELS..          0   1550000
TO FACILITY  3 PCLS..          0   2150000
TO FACILITY  5 CYLS..          0   8856000
TO FACILITY  6 RSLS..     166000    332000

                                                        TOTAL VARIABLE COST          130460
                                                               SYSTEM COST TOTAL          240333
```

```
FACILITY COMBINATION RANK     7            TOTAL COST          240391
              SUMMER DEAD-END . . . . . . . . . . .  1 FELS   3 PCLS   5 CYLS   6 RSLS   8 CSLS
              ALL-YEAR DEAD-END . . . . . . . . . .  9 FEDL 11 PCDL
              WINTER STORAGE  . . . . . . . . . . . 24 CYHT 27 CSHT

                                                          TOTAL FIXED COST              6400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                    SLUDGE DISTRIBUTION PATTERN

                                SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                       FROM//   1 GMLN     2 PWDH     3 NFLS     4 FFRI     5 PCBN
TO FACILITY  9 FEDL..               0          0          0     184000          0
TO FACILITY 11 PCDL..               0          0          0          0     894000
TO FACILITY 24 CYHT..               0    4207000    1224000          0          0
TO FACILITY 27 CSHT..          166000          0          0          0          0

                                SOURCE      TOTAL
                       FROM//   6 WLND
TO FACILITY  9 FEDL..               0     184000
TO FACILITY 11 PCDL..               0     894000
TO FACILITY 24 CYHT..          400000    5831000
TO FACILITY 27 CSHT..               0     166000

                                                     TOTAL VARIABLE COST            109177
                                                     SYSTEM COST TOTAL SO FAR           115577

SUMMER PORTION OF SYSTEM

                                    SLUDGE DISTRIBUTION PATTERN

                                SOURCE     SOURCE     SOURCE     SOURCE    STORAGE    STORAGE      TOTAL
                       FROM//   1 GMLN     2 PWDH     3 NFLS     6 WLND    24 CYHT    27 CSHT
TO FACILITY  1 FELS..               0    1550000          0          0          0          0    1550000
TO FACILITY  3 PCLS..               0    1750000          0     400000          0          0    2150000
TO FACILITY  5 CYLS..               0     907000    1224000          0    5831000          0    7962000
TO FACILITY  6 RSLS..          166000          0          0          0          0          0     166000
TO FACILITY  8 CSLS..               0          0          0          0          0     166000     166000

                                                     TOTAL VARIABLE COST            124814
                                                          SYSTEM COST TOTAL             240391
```

```
FACILITY COMBINATION RANK     8            TOTAL COST          240767
                SUMMER DEAD-END . . . . . . . . . .  1 FFLS  3 PCLS  5 CYLS  6 RSLS  7 WFLS
                ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 17 PDVF
                WINTER STORAGE  . . . . . . . . . . 22 PCHT

                                                                TOTAL FIXED COST          41200

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                             SLUDGE DISTRIBUTION PATTERN

                                SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                       FROM//   1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN
TO FACILITY  9 FEDL..                0          0    2396000     184000          0
TO FACILITY 17 PDVF..                0    5900000          0          0          0
TO FACILITY 22 PCHT..           166000    1257000      26000          0     447000

                                SOURCE      TOTAL
                       FROM//   6 WLND
TO FACILITY  9 FEDL..                0    2580000
TO FACILITY 17 PDVF..                0    5900000
TO FACILITY 22 PCHT..           400000    2296000

                                                          TOTAL VARIABLE COST         164457
                                                          SYSTEM COST TOTAL SO FAR       205657

SUMMER PORTION OF SYSTEM

                             SLUDGE DISTRIBUTION PATTERN

                                SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     STORAGE     TOTAL
                       FROM//   1 GMLN     2 PWDH     3 NFLS     5 PCBN     6 WLND     22 PCHT
TO FACILITY  1 FELS..                0    1257000      26000          0     267000          0   1550000
TO FACILITY  3 PCLS..                0          0          0          0          0    2150000   2150000
TO FACILITY  5 CYLS..                0          0          0          0     133000          0    133000
TO FACILITY  6 RSLS..           166000          0          0          0          0          0    166000
TO FACILITY  7 WFLS..                0          0          0     447000          0     146000    593000

                                                          TOTAL VARIABLE COST          35110
                                                               SYSTEM COST TOTAL         240767
```

```
FACILITY COMBINATION RANK     9           TOTAL COST           240923
              SUMMER DEAD-END . . . . . . . . . .  1 FFLS  3 PCLS  5 CYLS  6 RSLS  7 WFLS
              ALL-YEAR DEAD-END . . . . . . . . .  9 FFDL
              WINTER STORAGE  . . . . . . . . . . 24 CYHT 26 WFHT

                                                              TOTAL FIXED COST              6400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                         SLUDGE DISTRIBUTION PATTERN

                                SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                       FROM//   1 GMLN     2 PWDH     3 NFLS     4 FFRI     5 PCBN
TO FACILITY  9 FFDL..               0          0          0     184000          0
TO FACILITY 24 CYHT..          166000    4207000    1224000          0          0
TO FACILITY 26 WFHT..               0          0          0          0     447000

                                SOURCE      TOTAL
                       FROM//   6 WLND
TO FACILITY  9 FFDL..               0     184000
TO FACILITY 24 CYHT..          400000    5997000
TO FACILITY 26 WFHT..               0     447000

                                                    TOTAL VARIABLE COST           102369
                                                    SYSTEM COST TOTAL SO FAR         108769
SUMMER PORTION OF SYSTEM

                         SLUDGE DISTRIBUTION PATTERN

                                SOURCE     SOURCE     SOURCE     SOURCE     SOURCE    STORAGE    STORAGE      TOTAL
                       FROM//   1 GMLN     2 PWDH     3 NFLS     5 PCBN     6 WLND    24 CYHT    26 WFHT
TO FACILITY  1 FFLS..               0    1550000          0          0          0          0          0     550000
TO FACILITY  3 PCLS..               0    1303000          0     447000     400000          0          0    2150000
TO FACILITY  5 CYLS..               0    1354000    1224000          0          0    5997000          0    8575000
TO FACILITY  6 RSLS..          166000          0          0          0          0          0          0     166000
TO FACILITY  7 WFLS..               0          0          0          0          0          0     447000     447000

                                                    TOTAL VARIABLE COST           132154
                                                           SYSTEM COST TOTAL         240923
```

```
FACILITY COMBINATION RANK   10            TOTAL COST          240997
            SUMMER DEAD-END . . . . . . . . . . 1 FELS  3 PCLS  5 CYLS  6 RSLS  8 CSLS
            ALL-YEAR DEAD-END . . . . . . . . . 9 FEDL
            WINTER STORAGE  . . . . . . . . . . 22 PCHT 24 CYHT 27 CSHT

                                                               TOTAL FIXED COST           9600

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                 SLUDGE DISTRIBUTION PATTERN


                               SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                      FROM//   1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN
TO FACILITY  9 FEDL..               0          0          0     184000          0
TO FACILITY 22 PCHT..               0          0          0          0     447000
TO FACILITY 24 CYHT..               0    4207000    1224000          0          0
TO FACILITY 27 CSHT..          166000          0          0          0          0

                               SOURCE      TOTAL
                      FROM//   6 WLND
TO FACILITY  9 FEDL..               0     184000
TO FACILITY 22 PCHT..          400000     847000
TO FACILITY 24 CYHT..               0    5431000
TO FACILITY 27 CSHT..               0     166000

                                                        TOTAL VARIABLE COST          100937
                                                        SYSTEM COST TOTAL SO FAR       . 110537
SUMMER PORTION OF SYSTEM

                                 SLUDGE DISTRIBUTION PATTERN                   .

                               SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     STORAGE    STORAGE
                      FROM//   1 GMLN     2 PWDH     3 NFLS     5 PCBN     6 WLND    22 PCHT    24 CYHT
TO FACILITY  1 FELS..               0    1550000          0          0          0          0          0
TO FACILITY  3 PCLS..               0     456000          0     447000     400000     847000          0
TO FACILITY  5 CYLS..               0    2201000    1224000          0          0          0    5431000
TO FACILITY  6 RSLS..          166000          0          0          0          0          0          0
TO FACILITY  8 CSLS..               0          0          0          0          0          0          0

                              STORAGE      TOTAL
                      FROM//  27 CSHT
TO FACILITY  1 FELS..               0    1550000
TO FACILITY  3 PCLS..               0    2150000
TO FACILITY  5 CYLS..               0    8856000
TO FACILITY  6 RSLS..               0     166000
TO FACILITY  8 CSLS..          166000     166000

                                                        TOTAL VARIABLE COST          130460
                                                             SYSTEM COST TOTAL         240997
```

```
FACILITY COMBINATION RANK   11           TOTAL COST          241281
              SUMMER DEAD-END . . . . . . . . . . 1 FFLS  3 PCLS  4 PALS  5 CYLS  6 RSLS
              ALL-YEAR DEAD-END . . . . . . . . . 9 FFDL
              WINTER STORAGE  . . . . . . . . . . 23 PAHT 24 CYHT

                                                         TOTAL FIXED COST            6400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                        SLUDGE DISTRIBUTION PATTERN

                               SOURCE    SOURCE    SOURCE    SOURCE    SOURCE
                     FROM//    1 GMLN    2 PWDH    3 NFLS    4 FERI    5 PCBN
TO FACILITY  9 FFDL..               0         0         0    184000         0
TO FACILITY 23 PAHT..               0         0         0         0    447000
TO FACILITY 24 CYHT..          166000   4207000   1224000         0         0

                               SOURCE     TOTAL
                     FROM//    6 WLND
TO FACILITY  9 FFDL..               0    184000
TO FACILITY 23 PAHT..               0    447000
TO FACILITY 24 CYHT..          400000   5997000

                                                   TOTAL VARIABLE COST          102727
                                                   SYSTEM COST TOTAL SO FAR        109127

SUMMER PORTION OF SYSTEM

                        SLUDGE DISTRIBUTION PATTERN

                               SOURCE    SOURCE    SOURCE    SOURCE    SOURCE   STORAGE   STORAGE     TOTAL
                     FROM//    1 GMLN    2 PWDH    3 NFLS    5 PCBN    6 WLND   23 PAHT   24 CYHT
TO FACILITY  1 FFLS..               0   1550000         0         0         0         0         0   1550000
TO FACILITY  3 PCLS..               0   1303000         0    447000    400000         0         0   2150000
TO FACILITY  4 PALS..               0         0         0         0         0    447000         0    447000
TO FACILITY  5 CYLS..               0   1354000   1224000         0         0         0   5997000   8575000
TO FACILITY  6 RSLS..          166000         0         0         0         0         0         0    166000

                                                   TOTAL VARIABLE COST          132154
                                                        SYSTEM COST TOTAL          241281
```

```
FACILITY COMBINATION RANK   12            TOTAL COST          24134
              SUMMER DEAD-END . . . . . . . . . .  1 FFLS  3 PCLS  4 PALS  5 CYLS  6 RSLS
              ALL-YEAR DEAD-END . . . . . . . . .  9 FFDL 11 PCDL
              WINTER STORAGE  . . . . . . . . . . 23 PAHT 25 RSHT

                                                             TOTAL FIXED COST            6400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                         SLUDGE DISTRIBUTION PATTERN

                             SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                     FROM//  1 GMLN     2 PWDH     3 NFLS     4 FFRI     5 PCBN
TO FACILITY  9 FFDL..             0          0    2396000     184000          0
TO FACILITY 11 PCDL..             0          0          0          0          0
TO FACILITY 23 PAHT..             0          0          0          0     447000
TO FACILITY 25 RSHT..        166000    4207000      26000          0          0

                             SOURCE      TOTAL
                     FROM//  6 WLND
TO FACILITY  9 FFDL..             0    2580000
TO FACILITY 11 PCDL..        800000     800000
TO FACILITY 23 PAHT..             0     447000
TO FACILITY 25 RSHT..             0    4399000

                                                     TOTAL VARIABLE COST          134537
                                                     SYSTEM COST TOTAL SO FAR        140937

SUMMER PORTION OF SYSTEM

                         SLUDGE DISTRIBUTION PATTERN

                             SOURCE     SOURCE     SOURCE     SOURCE     STORAGE    STORAGE      TOTAL
                     FROM//  1 GMLN     2 PWDH     3 NFLS     5 PCBN     23 PAHT    25 RSHT
TO FACILITY  1 FFLS..             0    1550000          0          0           0          0    1550000
TO FACILITY  3 PCLS..             0    1703000          0     447000           0          0    2150000
TO FACILITY  4 PALS..             0          0          0          0      447000          0     447000
TO FACILITY  5 CYLS..             0     954000      26000          0           0          0     980000
TO FACILITY  6 RSLS..        166000          0          0          0           0    4399000    4565000

                                                     TOTAL VARIABLE COST          100404
                                                            SYSTEM COST TOTAL        241341
```

```
FACILITY COMBINATION RANK   13            TOTAL COST          241553
               SUMMER DEAD-END . . . . . . . . . .  1 FELS  3 PCLS  5 CYLS  6 RSLS
               ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 17 PDVF
               WINTER STORAGE  . . . . . . . . . . 22 PCHT 24 CYHT

                                                              TOTAL FIXED COST          44400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN


                              SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                     FROM//   1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN
TO FACILITY  9 FEDL..              0          0          0     184000          0
TO FACILITY 17 PDVF..              0    5900000          0          0          0
TO FACILITY 22 PCHT..              0          0          0          0     447000
TO FACILITY 24 CYHT..         166000    1257000    1224000          0          0

                              SOURCE      TOTAL
                     FROM//   6 WLND
TO FACILITY  9 FEDL..              0     184000
TO FACILITY 17 PDVF..              0    5900000
TO FACILITY 22 PCHT..         400000     847000
TO FACILITY 24 CYHT..              0    2647000

                                                       TOTAL VARIABLE COST          138723
                                                       SYSTEM COST TOTAL SO FAR         183123

SUMMER PORTION OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN

                              SOURCE     SOURCE     SOURCE     SOURCE     SOURCE    STORAGE    STORAGE      TOTAL
                     FROM//   1 GMLN     2 PWDH     3 NFLS     5 PCBN     6 WLND    22 PCHT    24 CYHT
TO FACILITY  1 FELS..              0     801000     749000          0          0          0          0    1550000
TO FACILITY  3 PCLS..              0     456000          0     447000     400000     847000          0    2150000
TO FACILITY  5 CYLS..              0          0     475000          0          0          0    2647000    3122000
TO FACILITY  6 RSLS..         166000          0          0          0          0          0          0     166000

                                                       TOTAL VARIABLE COST          58430
                                                            SYSTEM COST TOTAL          241553
```

```
FACILITY COMBINATION RANK   14             TOTAL COST           241971
              SUMMER DEAD-END . . . . . . . . . . 1 FELS  3 PCLS  5 CYLS  6 RSLS  7 WFLS
              ALL-YEAR DEAD-END . . . . . . . . . 9 FEDL
              WINTER STORAGE  . . . . . . . . . . 25 RSHT 26 WFHT

                                                              TOTAL FIXED COST           6400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                        SLUDGE DISTRIBUTION PATTERN


                            SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                    FROM//  1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN
TO FACILITY  9 FEDL..            0          0    2396000     184000          0
TO FACILITY 25 RSHT..       166000    4207000      26000          0          0
TO FACILITY 26 WFHT..            0          0          0          0     447000

                            SOURCE      TOTAL
                    FROM//  6 WLND
TO FACILITY  9 FEDL..            0    2580000
TO FACILITY 25 RSHT..            0    4399000
TO FACILITY 26 WFHT..       400000     847000

                                                         TOTAL VARIABLE COST          128359
                                                         SYSTEM COST TOTAL SO FAR        134759

SUMMER PORTION OF SYSTEM

                        SLUDGE DISTRIBUTION PATTERN

                            SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     STORAGE    STORAGE      TOTAL
                    FROM//  1 GMLN     2 PWDH     3 NFLS     5 PCBN     6 WLND     25 RSHT    26 WFHT
TO FACILITY  1 FELS..            0    1550000          0          0          0          0          0    1550000
TO FACILITY  3 PCLS..            0    1303000          0     447000     400000          0          0    2150000
TO FACILITY  5 CYLS..            0    1354000      26000          0          0          0          0    1380000
TO FACILITY  6 RSLS..       166000          0          0          0          0    4399000          0    4565000
TO FACILITY  7 WFLS..            0          0          0          0          0          0     847000     847000

                                                         TOTAL VARIABLE COST          107212
                                                               SYSTEM COST TOTAL       241971
```

```
FACILITY COMBINATION RANK   15            TOTAL COST          242279
             SUMMER DEAD-END . . . . . . . . . . .  1 FFLS  3 PCLS  5 CYLS  6 RSLS  7 WFLS  8 CSLS
             ALL-YEAR DEAD-END . . . . . . . . . .  9 FFDL 17 PDVF
             WINTER STORAGE  . . . . . . . . . . . 22 PCHT 27 CSHT

                                                                 TOTAL FIXED COST           44400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                    SLUDGE DISTRIBUTION PATTERN


                                SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                        FROM//  1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN
TO FACILITY  9 FFDL..                0          0    2396000     184000          0
TO FACILITY 17 PDVF..                0    5900000          0          0          0
TO FACILITY 22 PCHT..                0    1257000      26000          0     447000
TO FACILITY 27 CSHT..           156000          0          0          0          0

                                SOURCE      TOTAL
                        FROM//  6 WLND
TO FACILITY  9 FFDL..                0    2580000
TO FACILITY 17 PDVF..                0    5900000
TO FACILITY 22 PCHT..           400000    2130000
TO FACILITY 27 CSHT..                0     156000

                                                           TOTAL VARIABLE COST          164125
                                                           SYSTEM COST TOTAL SO FAR        208525

SUMMER PORTION OF SYSTEM

                                   SLUDGE DISTRIBUTION PATTERN

                                SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     STORAGE    STORAGE      TOTAL
                        FROM//  1 GMLN     2 PWDH     3 NFLS     5 PCBN     6 WLND     22 PCHT    27 CSHT
TO FACILITY  1 FFLS..                0    1257000      26000          0     267000          0          0     550000
TO FACILITY  3 PCLS..                0          0          0      20000          0    2130000          0    2150000
TO FACILITY  5 CYLS..                0          0          0          0     133000          0          0     133000
TO FACILITY  6 RSLS..           166000          0          0          0          0          0          0     166000
TO FACILITY  7 WFLS..                0          0          0     427000          0          0          0     427000
TO FACILITY  8 CSLS..                0          0          0          0          0          0     166000     166000

                                                          TOTAL VARIABLE COST           33754
                                                                SYSTEM COST TOTAL         242279
```

```
FACILITY COMBINATION RANK    6              TOTAL COST            242639
                SUMMER DEAD-END . . . . . . . . . .  1 FELS  3 PCLS   6 RSLS
                ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 17 PDVF
                WINTER STORAGE  . . . . . . . . . . 22 PCHT 25 RSHT

                                                             TOTAL FIXED COST           44400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN

                               SOURCE      SOURCE      SOURCE      SOURCE      SOURCE
                     FROM//    1 GMLN      2 PWDH      3 NFLS      4 FERI      5 PCBN
TO FACILITY  9 FEDL..              0           0     2396000      184000           0
TO FACILITY 17 PDVF..              0     5900000           0           0           0
TO FACILITY 22 PCHT..              0           0           0           0      447000
TO FACILITY 25 RSHT..         166000     1257000       26000           0           0

                               SOURCE      TOTAL
                     FROM//    6 WLND
TO FACILITY  9 FEDL..              0     2580000
TO FACILITY 17 PDVF..              0     5900000
TO FACILITY 22 PCHT..         400000      847000
TO FACILITY 25 RSHT..              0     1449000

                                                       TOTAL VARIABLE COST          162573
                                                       SYSTEM COST TOTAL SO FAR          206973

SUMMER PORTION OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN

                               SOURCE      SOURCE      SOURCE      SOURCE      SOURCE      STORAGE     STORAGE       TOTAL
                     FROM//    1 GMLN      2 PWDH      3 NFLS      5 PCBN      6 WLND      22 PCHT     25 RSHT
TO FACILITY  1 FELS..              0     1257000       26000           0           0           0           0     1283000
TO FACILITY  3 PCLS..              0           0           0      447000      400000      847000           0     1694000
TO FACILITY  6 RSLS..         156000           0           0           0           0           0     1449000     1605000

                                                       TOTAL VARIABLE COST          35666
                                                            SYSTEM COST TOTAL          242639
```

```
FACILITY COMBINATION RANK   17            TOTAL COST          243227
              SUMMER DEAD-END . . . . . . . . . . .  1 FFLS  3 PCLS  5 CYLS  6 RSLS  7 WFLS
              ALL-YEAR DEAD-END . . . . . . . . . .  9 FFDL
              WINTER STORAGE  . . . . . . . . . . . 24 CYHT 25 RSHT 26 WFHT

                                                          TOTAL FIXED COST             9600

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN


                            SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                   FROM//   1 GMLN     2 PWDH     3 NFLS     4 FFRI     5 PCBN
TO FACILITY  9 FFDL..            0          0          0     184000          0
TO FACILITY 24 CYHT..            0    4207000    1224000          0          0
TO FACILITY 25 RSHT..       166000          0          0          0          0
TO FACILITY 26 WFHT..            0          0          0          0     447000

                            SOURCE      TOTAL
                   FROM//   6 WLND
TO FACILITY  9 FFDL..            0     184000
TO FACILITY 24 CYHT..       400000    5831000
TO FACILITY 25 RSHT..            0     166000
TO FACILITY 26 WFHT..            0     447000

                                                     TOTAL VARIABLE COST          101473
                                                     SYSTEM COST TOTAL SO FAR         111073

SUMMER PORTION OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN

                            SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     STORAGE    STORAGE
                   FROM//   1 GMLN     2 PWDH     3 NFLS     5 PCBN     6 WLND     24 CYHT    25 RSHT
TO FACILITY  1 FFLS..            0    1550000          0          0          0          0          0
TO FACILITY  3 PCLS..            0    1303000          0     447000     400000          0          0
TO FACILITY  5 CYLS..            0    1354000    1224000          0          0    5831000          0
TO FACILITY  6 RSLS..       166000          0          0          0          0          0     166000
TO FACILITY  7 WFLS..            0          0          0          0          0          0          0

                           STORAGE      TOTAL
                   FROM//  26 WFHT
TO FACILITY  1 FFLS..            0    1550000
TO FACILITY  3 PCLS..            0    2150000
TO FACILITY  5 CYLS..            0    8409000
TO FACILITY  6 RSLS..            0     332000
TO FACILITY  7 WFLS..       447000     447000

                                                     TOTAL VARIABLE COST          132154
                                                         SYSTEM COST TOTAL          243227
```

```
FACILITY COMBINATION RANK  18            TOTAL COST          243584
            SUMMER DEAD-END . . . . . . . . . . .  1 FFLS  3 PCLS  4 PALS  5 CYLS  6 RSLS
            ALL-YEAR DEAD-END . . . . . . . . . .  9 FFDL
            WINTER STORAGE  . . . . . . . . . . . 23 PAHT 24 CYHT 25 RSHT

                                                           TOTAL FIXED COST              9600

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                       SLUDGE DISTRIBUTION PATTERN

                              SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                    FROM//    1 GMLN     2 PWDH     3 NFLS     4 FFRI     5 PCBN
TO FACILITY  9 FFDL..              0          0          0     184000          0
TO FACILITY 23 PAHT..              0          0          0          0     447000
TO FACILITY 24 CYHT..              0    4207000    1224000          0          0
TO FACILITY 25 RSHT..         166000          0          0          0          0

                              SOURCE      TOTAL
                    FROM//    6 WLND
TO FACILITY  9 FFDL..              0     184000
TO FACILITY 23 PAHT..              0     447000
TO FACILITY 24 CYHT..         400000    5831000
TO FACILITY 25 RSHT..              0     166000

                                                      TOTAL VARIABLE COST           101831
                                                      SYSTEM COST TOTAL SO FAR         111431

SUMMER PORTION OF SYSTEM

                       SLUDGE DISTRIBUTION PATTERN

                              SOURCE     SOURCE     SOURCE     SOURCE     SOURCE    STORAGE    STORAGE
                    FROM//    1 GMLN     2 PWDH     3 NFLS     5 PCBN     6 WLND    23 PAHT    24 CYHT
TO FACILITY  1 FFLS..              0    1550000          0          0          0          0          0
TO FACILITY  3 PCLS..              0    1303000          0     447000     400000          0          0
TO FACILITY  4 PALS..              0          0          0          0          0     447000          0
TO FACILITY  5 CYLS..              0    1354000    1224000          0          0          0    5831000
TO FACILITY  6 RSLS..         166000          0          0          0          0          0          0

                             STORAGE      TOTAL
                    FROM//   25 RSHT
TO FACILITY  1 FFLS..              0    1550000
TO FACILITY  3 PCLS..              0    2150000
TO FACILITY  4 PALS..              0     447000
TO FACILITY  5 CYLS..              0    8409000
TO FACILITY  6 RSLS..         166000     332000

                                                      TOTAL VARIABLE COST           132154
                                                          SYSTEM COST TOTAL            243584
```

```
FACILITY COMBINATION RANK   19            TOTAL COST          243784
                   SUMMER DEAD-END . . . . . . . . . .  1 FELS  3 PCLS  5 CYLS  6 RSLS
                   ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 11 PCDL 17 PDVF
                   WINTER STORAGE  . . . . . . . . . . 24 CYHT

                                                                TOTAL FIXED COST           41200

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                SLUDGE DISTRIBUTION PATTERN

                               SOURCE      SOURCE      SOURCE      SOURCE      SOURCE
                      FROM//   1 GMLN      2 PWDH      3 NFLS      4 FERI      5 PCBN
TO FACILITY  9 FEDL..               0           0           0      184000           0
TO FACILITY 11 PCDL..               0           0           0           0      894000
TO FACILITY 17 PDVF..               0     5900000           0           0           0
TO FACILITY 24 CYHT..          166000     1257000     1224000           0           0

                               SOURCE       TOTAL
                      FROM//   6 WLND
TO FACILITY  9 FEDL..               0      184000
TO FACILITY 11 PCDL..               0      894000
TO FACILITY 17 PDVF..               0     5900000
TO FACILITY 24 CYHT..          400000     3047000

                                                           TOTAL VARIABLE COST          146963
                                                           SYSTEM COST TOTAL SO FAR         188163

SUMMER PORTION OF SYSTEM

                                SLUDGE DISTRIBUTION PATTERN

                               SOURCE      SOURCE      SOURCE      SOURCE     STORAGE      TOTAL
                      FROM//   1 GMLN      2 PWDH      3 NFLS      6 WLND     24 CYHT
TO FACILITY  1 FELS..               0      326000     1224000           0           0    1550000
TO FACILITY  3 PCLS..               0      931000           0      400000           0    1331000
TO FACILITY  5 CYLS..               0           0           0           0     3047000    3047000
TO FACILITY  6 RSLS..          166000           0           0           0           0     166000

                                                           TOTAL VARIABLE COST           55621
                                                                SYSTEM COST TOTAL          243784
```

```
FACILITY COMBINATION RANK   20            TOTAL COST          243857
               SUMMER DEAD-END . . . . . . . . . .  1 FFLS  3 PCLS  5 CYLS  6 RSLS
               ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 17 PDVF
               WINTER STORAGE  . . . . . . . . . . 22 PCHT 24 CYHT 25 RSHT

                                                                TOTAL FIXED COST          47600

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                     SLUDGE DISTRIBUTION PATTERN


                                  SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                         FROM//   1 GMLN     2 PWDH     3 NFLS     4 FFRI     5 PCBN
TO FACILITY  9 FEDL..          0          0          0     184000          0
TO FACILITY 17 PDVF..          0    5900000          0          0          0
TO FACILITY 22 PCHT..          0          0          0          0     447000
TO FACILITY 24 CYHT..          0    1257000    1224000          0          0
TO FACILITY 25 RSHT..     166000          0          0          0          0

                                  SOURCE      TOTAL
                         FROM//   6 WLND
TO FACILITY  9 FEDL..          0     184000
TO FACILITY 17 PDVF..          0    5900000
TO FACILITY 22 PCHT..     400000     847000
TO FACILITY 24 CYHT..          0    2481000
TO FACILITY 25 RSHT..          0     166000

                                                        TOTAL VARIABLE COST          137827
                                                        SYSTEM COST TOTAL SO FAR   .    185427

SUMMER PORTION OF SYSTEM

                                     SLUDGE DISTRIBUTION PATTERN

                                  SOURCE     SOURCE     SOURCE     SOURCE     SOURCE    STORAGE   STORAGE
                         FROM//   1 GMLN     2 PWDH     3 NFLS     5 PCBN     6 WLND    22 PCHT   24 CYHT
TO FACILITY  1 FFLS..          0     801000     749000          0          0          0         0
TO FACILITY  3 PCLS..          0     456000          0     447000     400000     847000         0
TO FACILITY  5 CYLS..          0          0     475000          0          0          0   248 000
TO FACILITY  6 RSLS..     166000          0          0          0          0          0         0

                                 STORAGE      TOTAL
                         FROM//  25 RSHT
TO FACILITY  1 FFLS..          0    1550000
TO FACILITY  3 PCLS..          0    2150000
TO FACILITY  5 CYLS..          0    2956000
TO FACILITY  6 RSLS..     166000     332000

                                                        TOTAL VARIABLE COST           58430
                                                                SYSTEM COST TOTAL       243857


END OF CASE
STATISTICS..       FACSET=        1976     NSTOR=        1218     LINCAL=       3106     NOSMMR=          0
```

```
CASE NUMBER  2

             DATA CASE FOR 1980

ANNUAL PRODUCTION AT SOURCES          1 GMLN    5400000      2 PWDH   19770000      3 NFLS   11400000      4 FERI    4 55000
                                      5 PCBN    3210000      6 WLND    7965000

FACILITY PARAMETERS                LIM         CONF             CONV           DAMF         DAMV          VRED
                    1 FFLS      1550000           0       0.0                     0    0.0            0.0
                    2 NFLS     20000000           0       3.500E-03               0    1.500E-03      0.0
                    3 PCLS      2150000           0       0.0                     0    0.0            0.0
                    4 PALS     20000000           0       3.500E-03               0    1.500E-03      0.0
                    5 CYLS     20000000           0       3.500E-03               0    1.500E-03      0.0
                    6 RSLS     20000000           0       3.500E-03               0    1.500E-03      0.0
                    7 WFLS     20000000           0       3.500E-03               0    1.500E-03      0.0
                    8 CSLS     20000000           0       3.500E-03               0    1.500E-03      0.0
                    9 FFDL      2580000           0       5.222E-03               0    4.680E-06      2.600E-01
                   10 NFDL      9000000           0       1.300E-02               0    2.805E-03      2.600E-01
                   11 PCDL      3550000           0       5.222E-03               0    4.680E-06      2.600E-01
                   12 PADL      9000000           0       1.300E-02               0    2.805E-03      2.600E-01
                   13 CYDL      9000000           0       1.300E-02               0    2.805E-03      2.600E-01
                   14 RSDL      9000000           0       1.300E-02               0    2.805E-03      2.600E-01
                   15 WFDL      9000000           0       1.300E-02               0    2.805E-03      2.600E-0
                   16 CSDL      9000000           0       1.300E-02               0    2.805E-03      2.600E-01
                   17 PDVF      8850000        3000       0.0                 35000    1.032E-02      0.0
                   18 NFVF      3675010        3000       0.0                 35000    1.773E-02      0.0
                   19 WDVF      2700000        3000       0.0                 35000    2.614E-02      0.0
                   20 FFHT     27000000        3000       1.399E-03             200    7.400E-06      1.000E 00
                   21 NFHT     27000000        3000       2.304E-03             200    7.400E-06      1.000E 00
                   22 PCHT     27000000        3000       1.399E-03             200    7.400E-06      1.000E 00
                   23 PAHT     27000000        3000       1.399E-03             200    7.400E-06      1.000E 00
                   24 CYHT     27000000        3000       1.399E-03             200    7.400E-06      1.000E 00
                   25 RSHT     27000000        3000       1.399E-03             200    7.400E-06      1.000E 00
                   26 WFHT     27000000        3000       1.399E-03             200    7.400E-06      1.000E 00
                   27 CSHT     27000000        3000       1.399E-03             200    7.400E-06      1.000E 00

LIQLF=1   WINTER=0.50000000

MODE OF DISTRIBUTION COST ARRAY CALCULATION IS IDST
HAULAGE FORMULAS . . . .
 1 COST PER UNIT VOLUME =  6.0000E-03 PLUS  6.0000E-03 TIMES TRIP LENGTH
 2 COST PER UNIT VOLUME =  0.0        PLUS  7.2000E-05 TIMES TRIP LENGTH
 3 COST PER UNIT VOLUME =  0.0        PLUS  1.5000E 00 TIMES TRIP LENGTH

                                                UNI TRANS  UNIT VARI                  UNI TRANS  UNIT VARI                  UNI TRANS  UNIT VARI
                                      DISTANCE  PORT COST  ABLE COST        DISTANCE  PORT COST  ABLE COST        DISTANCE  PORT COST  ABLE COST
USING HAULAGE FORMULA..          1                                   1                                   1
                                 1                                   1                                   1
TO FACILITY  1 FROM SOURCE       1.  2.1000      0.0186     0.0186   2.  1.4000      0.0144     0.0144   3.  0.9000      0.0114     0.0114
                                 4.  0.2667      0.0076     0.0076   5.  1.3333      0.0140     0.0140   6.  1.3333      0.0140     0.0140
USING HAULAGE FORMULA..          1                                                                       1
                                 1                                   1                                   1
TO FACILITY  2 FROM SOURCE       1.  1.7500      0.0165     0.0215   2.  1.5000      0.0150     0.0200   3.  1.2000      0.0132     0.0182
                                 4.  0.6667      0.0112     0.0162   5.  0.9333      0.0116     0.0166   6.  0.6667      0.0100     0.0150
USING HAULAGE FORMULA..          1                                   1                                   1
                                 1                                                                       
TO FACILITY  3 FROM SOURCE       1.  1.9500      0.0177     0.0177   2.  1.7667      0.0166     0.0166   3.  1.6667      0.0160     0.0160
                                 4.  1.7333      0.0164     0.0164   5.  0.4000      0.0084     0.0084   6.  0.5000      0.0090     0.0090
USING HAULAGE FORMULA..          1                                                                       1
```

```
                                    1                                               2                                        1
                                    1                                               1
TO FACILITY  5 FROM FACILITY 20.  1.2000      0.0132      0.0182 21.  0.8000      0.0108      0.0158 22.  1.1000      0.0126      0.0176
                             23.  1.3000      0.0120      0.0170 24.  0.2500      0.0000      0.0050 25.  1.4000      0.0144      0.0194
                             26.  1.4667      0.0148      0.0198 27.  2.0000      0.0180      0.0230
USING HAULAGE FORMULA..             !                                               !                                        1
                                    1                                               .                                        2
                                    !                                               .
TO FACILITY  6 FROM FACILITY 20.  1.7500      0.0165      0.0215 21.  1.6667      0.0160      0.0210 22.  1.2667      0.0136      0.0186
                             23.  1.9333      0.0176      0.0226 24.  1.4000      0.0144      0.0194 25.  0.2500      0.0000      0.0050
                             26.  0.9333      0.0116      0.0166 27.  1.2667      0.0136      0.0186
USING HAULAGE FORMULA..             1                                               1                                        1
                                    .                                               .                                        1
                                    2.                                              :
TO FACILITY  7 FROM FACILITY 20.  1.5333      0.0152      0.0202 21.  1.5333      0.0152      0.0202 22.  0.5333      0.0092      0.0142
                             23.  1.8000      0.0168      0.0218 24.  1.4667      0.0148      0.0198 25.  0.9333      0.0116      0.0166
                             26.  0.2500      0.0000      0.0050 27.  1.6000      0.0156      0.0206
USING HAULAGE FORMULA..             1                                               1                                        1
                                    1                                               '                                        1
                                    1                                               2
TO FACILITY  8 FROM FACILITY 20.  2.4500      0.0207      0.0257 21.  2.7333      0.0224      0.0274 22.  2.0667      0.0184      0.0234
                             23.  2.5667      0.0214      0.0264 24.  2.0000      0.0180      0.0230 25.  1.2667      0.0136      0.0186
                             26.  1.6000      0.0156      0.0206 27.  0.2500      0.0000      0.0050

FOR COMPUTATION THE DATA IS BEING MODIFIED AS FOLLOWS..

VARIABLE COSTS ARE MULTIPLIED BY      10000
SLUDGE QUANTITIES AND LIMITS ARE DIVIDED BY       1000
FIXED COSTS ARE MULTIPLIED BY 1.0000000E 01
THE WINTER FACTOR IS CONVERTED TO THE RATIO OF THE TWO NUMBERS        50  OVER       100
THE WEIGHTING FACTOR THAT WAS READ IN, 0.0
 YIELDS MULTIPLICATION OF VARIABLE ALL-YEAR FACILITY COSTS BY 100  OVER 100
 FOR PURPOSES OF COST COMPARISON IN THE WINTER SYSTEM.
FOR EASY READING ALL SOLUTIONS WILL BE PRINTED OUT IN TERMS OF THE ORIGINAL DATA.
```

```
ALL OF THE 134217727  POSSIBLE COMBINATIONS OF FACILITIES WILL BE CONSIDERED.
EVERY        300 TH. COMBINATION REACHING THE SURVEY WILL BE DONE WITH NETOUT FOR
DETAILED TREATMENT INCLUDING PRINTOUT OF BEST SLUDGE DISTRIBUTION PATTERNS AND COSTS.
DATA DUMP WILL OCCUR AT INTERVALS OF       1000

COST SURVEY BEGINNING WITH CURRENT MINIMUM TOTAL SYSTEM COST = 999999999
```

```
FACILITY   1FELS IS INCLUDED IN EVERY COMBINATION
FACILITY   2NELS IS INCLUDED IN EVERY COMBINATION
FACILITY   3PCLS IS INCLUDED IN EVERY COMBINATION
FACILITY   4PALS IS INCLUDED IN EVERY COMBINATION
FACILITY   5CYLS IS INCLUDED IN EVERY COMBINATION
FACILITY   6RSLS IS INCLUDED IN EVERY COMBINATION
FACILITY   7WFLS IS INCLUDED IN EVERY COMBINATION
FACILITY   8CSLS IS INCLUDED IN EVERY COMBINATION
FACILITY   9FEDL IS INCLUDED IN EVERY COMBINATION
FACILITY  10NEDL IS INCLUDED IN EVERY COMBINATION
FACILITY  11PCDL IS INCLUDED IN EVERY COMBINATION
FACILITY  12PADL IS INCLUDED IN EVERY COMBINATION
FACILITY  13CYDL IS INCLUDED IN EVERY COMBINATION
FACILITY  14RSDL IS INCLUDED IN EVERY COMBINATION
FACILITY  15WFDL IS INCLUDED IN EVERY COMBINATION
FACILITY  16CSDL IS INCLUDED IN EVERY COMBINATION

THE MAXIMUM NUMBER OF FACILITIES OF ONE KIND IN ANY COMBINATION IS
                  6 SUMMER DEADEND
                  0 ALL-YEAR INTERMEDIATE
                  6 ALL-YEAR DEADEND
                  6 WINTER STORAGE




///////// A FACILITY SUBSET IS BEING DONE WITH NETOUT. THIS IS THE        500  TH. SUBSET IN THE SURVEY.
FACILITY NAMES
                  SUMMER DEAD-END . . . . . . . . . .  1 FELS  2 NELS  3 PCLS  4 PALS  5 CYLS  6 RSLS  7 WFLS  8 CSLS
                  ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 10 NEDL 11 PCDL 12 PADL 13 CYDL 14 RSDL 15 WFDL 16 CSDL 17 PDVF
                  WINTER STORAGE  . . . . . . . . . . 20 FEHT 21 NEHT 25 RSHT

                                                               TOTAL FIXED COST            47600

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                SLUDGE DISTRIBUTION PATTERN


                                  SOURCE      SOURCE      SOURCE      SOURCE      SOURCE
                          FROM//  1 GMLN      2 PWDH      3 NFLS      4 FERT      5 PCBN
TO FACILITY  9 FEDL..                  0           0           0           0           0
TO FACILITY 10 NEDL..                  0           0           0           0           0
TO FACILITY 11 PCDL..                  0           0           0           0     3210000
TO FACILITY 12 PADL..                  0           0           0           0           0
TO FACILITY 13 CYDL..                  0           0           0           0           0
TO FACILITY 14 RSDL..                  0           0           0           0           0
TO FACILITY 15 WFDL..                  0           0           0           0           0
TO FACILITY 16 CSDL..                  0           0           0           0           0
TO FACILITY 17 PDVF..                  0     8850000           0           0           0
TO FACILITY 20 FEHT..                  0     5460000     5700000     2073000           0
TO FACILITY 21 NEHT..                  0           0           0           0           0
TO FACILITY 25 RSHT..            2700000           0           0           0           0
```

```
                             STORAGE   STORAGE     TOTAL
                      FROM// 24 CYHT   25 RSHT
TO FACILITY  1 FFLS..           0         0     1550000
TO FACILITY  2 NFLS..           0         0     7346000
TO FACILITY  3 PCLS..           0         0     2150000
TO FACILITY  4 PALS..           0         0    10413000
TO FACILITY  5 CYLS..     5700000         0    20000000
TO FACILITY  6 RSLS..           0   2700000     5400000
TO FACILITY  7 WFLS..           0         0     5043000
TO FACILITY  8 CSLS..           0         0           0

                                                              TOTAL VARIABLE COST          696937
                                                                  SYSTEM COST TOTAL          10886.8
```

```
THE SURVEY IS FINISHED.        20 SOLUTIONS HAVE BEEN RETAINED, WITH TOTAL COSTS FROM         883527  TO          910203 .
THERE WERE SOME SOLUTIONS FROM          910203  TO          983527 ,
BUT IT WAS SPECIFIED NOT TO RETAIN MORE THAN          20  SOLUTIONS.
```

```
FACILITY COMBINATION RANK     1             TOTAL COST          883527
                  SUMMER DEAD-END . . . . . . . . . . . 1 FELS  2 NFLS  3 PCLS  5 CYLS  6 RSLS
                  ALL-YEAR DEAD-END . . . . . . . . . . 9 FEDL 11 PCDL 17 PDVF
                  WINTER STORAGE  . . . . . . . . . . . 24 CYHT 25 RSHT

                                                                 TOTAL FIXED COST          44400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN


                                    SOURCE      SOURCE      SOURCE      SOURCE      SOURCE
                          FROM//    1 GMLN      2 PWDH      3 NFLS      4 FERI      5 PCBN
TO FACILITY  9 FEDL..            0           0           0     2580000           0
TO FACILITY 11 PCDL..            0           0           0           0     3210000
TO FACILITY 17 PDVF..            0     8850000           0           0           0
TO FACILITY 24 CYHT..            0     5460000     5700000      788000           0
TO FACILITY 25 RSHT..      2700000           0           0           0           0

                                    SOURCE       TOTAL
                          FROM//    6 WLND
TO FACILITY  9 FEDL..            0     2580000
TO FACILITY 11 PCDL..            0     3210000
TO FACILITY 17 PDVF..            0     8850000
TO FACILITY 24 CYHT..      3983000    15931000
TO FACILITY 25 RSHT..            0     2700000

                                                       TOTAL VARIABLE COST           452485
                                                       SYSTEM COST TOTAL SO FAR         496885

SUMMER PORTION OF SYSTEM

                              SLUDGE DISTRIBUTION PATTERN

                                    SOURCE      SOURCE      SOURCE      SOURCE      SOURCE     STORAGE     STORAGE       TOTAL
                          FROM//    1 GMLN      2 PWDH      3 NFLS      4 FERI      6 WLND     24 CYHT     25 RSHT
TO FACILITY  1 FELS..            0           0      762000      788000           0           0           0     1550000
TO FACILITY  2 NFLS..            0           0      669000           0     1833000           0           0     2702000
TO FACILITY  3 PCLS..            0           0           0           0     2150000           0           0     2150000
TO FACILITY  5 CYLS..            0           0     4069000           0           0    15931000           0    20000000
TO FACILITY  6 RSLS..      2700000     5460000           0           0           0           0     2700000    10360000

                                                       TOTAL VARIABLE COST           386642
                                                             SYSTEM COST TOTAL          883527
```

```
FACILITY COMBINATION RANK   20          TOTAL COST          910203
             SUMMER DEAD-END . . . . . . . . . .  1 FELS  2 NELS  3 PCLS  4 PALS  5 CYLS  6 RSLS  7 WFLS  8 CSLS
             ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 17 PDVF
             WINTER STORAGE  . . . . . . . . . . 21 NEHT 23 PAHT 24 CYHT 27 CSHT

                                                               TOTAL FIXED COST          50800

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                    SLUDGE DISTRIBUTION PATTERN


                                 SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                       FROM//    1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN
TO FACILITY  9 FEDL..                 0          0          0    2580000          0
TO FACILITY 17 PDVF..                 0    8850000          0          0          0
TO FACILITY 21 NEHT..                 0          0          0     788000          0
TO FACILITY 23 PAHT..                 0          0          0          0    1605000
TO FACILITY 24 CYHT..                 0    5460000    5700000          0          0
TO FACILITY 27 CSHT..           2700000          0          0          0          0

                                 SOURCE      TOTAL
                       FROM//    6 WLND
TO FACILITY  9 FEDL..                 0    2580000
TO FACILITY 17 PDVF..                 0    8850000
TO FACILITY 21 NEHT..                 0     788000
TO FACILITY 23 PAHT..                 0    1605000
TO FACILITY 24 CYHT..           3983000   15143000
TO FACILITY 27 CSHT..                 0    2700000
                                                           TOTAL VARIABLE COST         435799   *
                                                           SYSTEM COST TOTAL SO FAR        486599

SUMMER PORTION OF SYSTEM

                                    SLUDGE DISTRIBUTION PATTERN

                                 SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     SOURCE    STORAGE    STORAGE
                       FROM//    1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN     6 WLND    21 NEHT    23 PAHT
TO FACILITY  1 FELS..                 0          0     762000     788000          0          0          0          0
TO FACILITY  2 NELS..                 0    5460000      81000          0          0    1833000          0          0
TO FACILITY  3 PCLS..                 0          0          0          0          0    2150000          0          0
TO FACILITY  4 PALS..                 0          0          0          0          0          0     788000    1605000
TO FACILITY  5 CYLS..                 0          0    4857000          0          0          0          0          0
TO FACILITY  6 RSLS..           2700000          0          0          0          0          0          0          0
TO FACILITY  7 WFLS..                 0          0          0          0    1605000          0          0          0
TO FACILITY  8 CSLS..                 0          0          0          0          0          0          0          0

                                STORAGE    STORAGE      TOTAL
                       FROM//   24 CYHT    27 CSHT
TO FACILITY  1 FELS..                 0          0    1550000
TO FACILITY  2 NELS..                 0          0    7374000
TO FACILITY  3 PCLS..                 0          0    2150000
TO FACILITY  4 PALS..                 0          0    2393000
TO FACILITY  5 CYLS..          15143000          0   20000000
TO FACILITY  6 RSLS..                 0          0    2700000
TO FACILITY  7 WFLS..                 0          0    1605000
TO FACILITY  8 CSLS..                 0    2700000    2700000    TOTAL VARIABLE COST          423604
END OF CASE                                                             SYSTEM COST TOTAL         910203
STATISTICS..        FACSET=        1976      NSTOR=         327      LINCAL=        3516      NOSMMP=           0
```

```
CASE NUMBER  3

         DATA CASE FOR 1990

ANNUAL PRODUCTION AT SOURCES          1 GMLN     6900000      2 PWDH    24525000      3 NFLS    14250000      4 FERI     699[illegible]000
                                      5 PCBN     4425000      6 WLND     9720000

FACILITY PARAMETERS           LIM          CONF         CONV            OAMF         OAMV            VRED
                 1 FELS     1550000           0      0.0                  0       0.0             0.0
                 2 NFLS    20000000           0      3.500E-03            0       1.500E-03       0.0
                 3 PCLS     2150000           0      0.0                  0       0.0             0.0
                 4 PALS    20000000           0      3.500E-03            0       1.500E-03       0.0
                 5 CYLS    20000000           0      3.500E-03            0       1.500E-03       0.0
                 6 RSLS    20000000           0      3.500E-03            0       1.500E-03       0.0
                 7 WFLS    20000000           0      3.500E-03            0       1.500E-03       0.0
                 8 CSLS    20000000           0      3.500E-03            0       1.500E-03       0.0
                 9 FEOL     2580000           0      5.222E-03            0       4.680E-05       2.600E-01
                10 NFOL     9000000           0      1.300E-02            0       2.805E-03       2.600E-01
                11 PCOL     3580000           0      5.222E-03            0       4.680E-05       2.600E-01
                12 PAOL     9000000           0      1.300E-02            0       2.805E-03       2.600E-01
                13 CYOL     9000000           0      1.300E-02            0       2.805E-03       2.600E-01
                14 RSOL     9000000           0      1.300E-02            0       2.805E-03       2.600E-01
                15 WFOL     9000000           0      1.300E-02            0       2.805E-03       2.600E-01
                16 CSOL     9000000           0      1.300E-02            0       2.805E-03       2.600E-01
                17 PDVF    11800000        3000      0.0              35000       1.032E-02       0.0
                18 NFVF     4900000        3000      0.0              35000       1.773E-02       0.0
                19 WDVF     3600000        3000      0.0              35000       2.614E-02       0.0
                20 FEHT    27000000        3000      1.399E-03          200       7.400E-06       1.000E 00
                21 NEHT    27000000        3000      2.304E-03          200       7.400E-06       1.000E 00
                22 PCHT    27000000        3000      1.399E-03          200       7.400E-06       1.000E 00
                23 PAHT    27000000        3000      1.399E-03          200       7.400E-06       1.000E 00
                24 CYHT    27000000        3000      1.399E-03          200       7.400E-06       1.000E 00
                25 RSHT    27000000        2000      1.399E-03          200       7.400E-06       1.000E 00
                26 WFHT    27000000        3000      1.399E-03          200       7.400E-06       1.000E 00
                27 CSHT    27000000        3000      1.399E-03          200       7.400E-06       1.000E 00
LICLF=1  WINTER=0.50000000

MODE OF DISTRIBUTION COST ARRAY CALCULATION IS IDST
HAULAGE FORMULAS . . . .
 1 COST PER UNIT VOLUME =  6.0000E-03 PLUS  6.0000E-03 TIMES TRIP LENGTH
 2 COST PER UNIT VOLUME =  0.0        PLUS  7.2000E-05 TIMES TRIP LENGTH
 3 COST PER UNIT VOLUME =  0.0        PLUS  1.5000E 00 TIMES TRIP LENGTH

                                         UNI TRANS  UNIT VARI                  UNI TRANS  UNIT VARI                  UNI TRANS  UNIT VARI
                                DISTANCE PORT COST  ABLE COST       DISTANCE   PORT COST  ABLE COST      DISTANCE    PORT COST  ABLE COST
USING HAULAGE FORMULA..      1                                  1                                    1
                             1                                  1                                    1
TO FACILITY  1 FROM SOURCE   1.  2.1000    0.0166     0.0186    2.  1.4000     0.0144     0.0144     3.  0.9000      [illegible]  [illegible]
                             4.  0.2667    0.0076     0.0076    5.  1.3333     0.0100     0.0140     6.  1.3333      0.0140     0.0140
USING HAULAGE FORMULA..      1                                  1                                    1
                             1                                  1                                    1
TO FACILITY  2 FROM SOURCE   1.  1.7500    0.0165     0.0215    2.  1.5000     0.0150     0.0200     3.  1.2000      0.0132     0.0162
                             4.  0.8667    0.0112     0.0162    5.  0.9333     0.0116     0.0166     6.  0.6667      [illegible]  0.0150
USING HAULAGE FORMULA..      1                                  1                                    1
                             1                                  1                                    1
TO FACILITY  3 FROM SOURCE   1.  1.9500    0.0177     0.0177    2.  1.7667     0.0166     0.0166     3.  1.6667      0.0160     0.0160
                             4.  1.7333    0.0164     0.0164    5.  0.4333     0.0084     0.0084     6.  0.5000      0.0050     [illegible]
USING HAULAGE FORMULA..      1                                                                       1
```

```
                                 1                                2                                      1
                                 1
TO FACILITY  5 FROM FACILITY 20.  1.2000      0.0132      0.0182 21.  0.8000      0.0108      0.0158 22.  1.1000      0.0126      0.0176
                             23.  1.0000      0.0120      0.0170 24.  0.2500      0.0000      0.0050 25.  1.4000      0.0144      0.0194
                             26.  1.4667      0.0148      0.0198 27.  2.0000      0.0180      0.0230
USING HAULAGE FORMULA..          1                                1                                      1
                                 :                                                                       2
                                 1                                :
TO FACILITY  6 FROM FACILITY 20.  1.7500      0.0165      0.0215 21.  1.6667      0.0160      0.0210 22.  1.2667      0.0136      0.0186
                             23.  1.9333      0.0176      0.0226 24.  1.4000      0.0144      0.0194 25.  0.2500      0.0000      0.0050
                             26.  0.9333      0.0116      0.0165 27.  1.2667      0.0136      0.0186
USING HAULAGE FORMULA..          1                                :                                      1
                                 :                                :                                      1
                                 2                                1
TO FACILITY  7 FROM FACILITY 20.  1.5333      0.0152      0.0202 21.  1.5333      0.0152      0.0202 22.  0.5333      0.0092      0.0142
                             23.  1.8000      0.0168      0.0218 24.  1.4667      0.0148      0.0198 25.  0.9333      0.0116      0.0166
                             26.  0.2500      0.0000      0.0050 27.  1.6000      0.0156      0.0206
USING HAULAGE FORMULA..          1                                :                                      1
                                 1                                1                                      1
                                 1                                2
TO FACILITY  8 FROM FACILITY 20.  2.4500      0.0207      0.0257 21.  2.7333      0.0224      0.0274 22.  2.0667      0.0184      0.0234
                             23.  2.5667      0.0214      0.0264 24.  2.0000      0.0180      0.0230 25.  1.2667      0.0136      0.0186
                             26.  1.6000      0.0156      0.0206 27.  0.2500      0.0000      0.0050

FOR COMPUTATION THE DATA IS BEING MODIFIED AS FOLLOWS..

VARIABLE COSTS ARE MULTIPLIED BY      10000
SLUDGE QUANTITIES AND LIMITS ARE DIVIDED BY       1000
FIXED COSTS ARE MULTIPLIED BY 1.0000000E 01
THE WINTER FACTOR IS CONVERTED TO THE RATIO OF THE TWO NUMBERS         50  OVER       100
THE WEIGHTING FACTOR THAT WAS READ IN, 0.0
 YIELDS MULTIPLICATION OF VARIABLE ALL-YEAR FACILITY COSTS BY 100  OVER 100
 FOR PURPOSES OF COST COMPARISON IN THE WINTER SYSTEM.
FOR EASY READING ALL SOLUTIONS WILL BE PRINTED OUT IN TERMS OF THE ORIGINAL DATA.




ALL OF THE 134217727  POSSIBLE COMBINATIONS OF FACILITIES WILL BE CONSIDERED.
EVERY        300 TH. COMBINATION REACHING THE SURVEY WILL BE DONE WITH NETOUT FOR
DETAILED TREATMENT INCLUDING PRINTOUT OF BEST SLUDGE DISTRIBUTION PATTERNS AND COSTS.
DATA DUMP WILL OCCUR AT INTERVALS OF       1000

COST SURVEY BEGINNING WITH CURRENT MINIMUM TOTAL SYSTEM COST = 999999999
```

```
FACILITY  1FELS IS INCLUDED IN EVERY COMBINATION
FACILITY  2NFLS IS INCLUDED IN EVERY COMBINATION
FACILITY  3PCLS IS INCLUDED IN EVERY COMBINATION
FACILITY  4PALS IS INCLUDED IN EVERY COMBINATION
FACILITY  5CYLS IS INCLUDED IN EVERY COMBINATION
FACILITY  6RSLS IS INCLUDED IN EVERY COMBINATION
FACILITY  7WFLS IS INCLUDED IN EVERY COMBINATION
FACILITY  8CSLS IS INCLUDED IN EVERY COMBINATION
FACILITY  9FEDL IS INCLUDED IN EVERY COMBINATION
FACILITY 10NFDL IS INCLUDED IN EVERY COMBINATION
FACILITY 11PCDL IS INCLUDED IN EVERY COMBINATION
FACILITY 12PADL IS INCLUDED IN EVERY COMBINATION
FACILITY 13CYDL IS INCLUDED IN EVERY COMBINATION
FACILITY 14RSDL IS INCLUDED IN EVERY COMBINATION
FACILITY 15WFDL IS INCLUDED IN EVERY COMBINATION
FACILITY 16CSDL IS INCLUDED IN EVERY COMBINATION

THE MAXIMUM NUMBER OF FACILITIES OF ONE KIND IN ANY COMBINATION IS
                  6 SUMMER DEADEND
                  0 ALL-YEAR INTERMEDIATE
                  6 ALL-YEAR DEADEND
                  6 WINTER STORAGE




////////// A FACILITY SUBSET IS BEING DONE WITH NETCUT. THIS IS THE       300  TH. SUBSET IN THE SURVEY.
FACILITY NAMES
                  SUMMER DEAD-END . . . . . . . . . .  1 FELS  2 NFLS  3 PCLS  4 PALS  5 CYLS  6 RSLS  7 WFLS  8 CSLS
                  ALL-YEAR DEAD-END . . . . . . . . .  9 FEDL 10 NFDL 11 PCDL 12 PADL 13 CYDL 14 RSDL 15 WFDL 16 CSDL 17 POVF
                  WINTER STORAGE  . . . . . . . . . . 20 FEHT 21 NFHT 25 RSHT

                                                                   TOTAL FIXED COST          47600

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                   SLUDGE DISTRIBUTION PATTERN


                              SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                     FROM//   1 GMLN     2 PWDH     3 NFLS     4 FERI     5 PCBN
TO FACILITY  9 FEDL..              0          0          0          0          0
TO FACILITY 10 NFDL..              0          0          0          0          0
TO FACILITY 11 PCDL..              0          0          0          0    3580000
TO FACILITY 12 PADL..              0          0          0          0          0
TO FACILITY 13 CYDL..              0          0          0          0          0
TO FACILITY 14 RSDL..              0          0          0          0          0
TO FACILITY 15 WFDL..              0          0          0          0          0
TO FACILITY 16 CSDL..              0          0          0          0          0
TO FACILITY 17 POVF..              0   11800000          0          0          0
TO FACILITY 20 FEHT..              0    6363000    7125000    2498000          0
TO FACILITY 21 NFHT..              0          0          0          0     423000
TO FACILITY 25 RSHT..        3450000          0          0          0          0
```

```
                               STORAGE   STORAGE     TOTAL
                       FROM//  24 CYHT   25 RSHT
TO FACILITY  1 FFLS..             0         0      1550000
TO FACILITY  2 NFLS..             0         0     13871000
TO FACILITY  3 PCLS..             0         0      2150000
TO FACILITY  4 PALS..             0         0     13211000
TO FACILITY  5 CYLS..       7125000         0     20000000
TO FACILITY  6 RSLS..             0   3450000      6900000
TO FACILITY  7 WFLS..             0         0      7136000
TO FACILITY  8 CSLS..             0         0            0

                                                                      TOTAL VARIABLE COST          884409
                                                                            SYSTEM COST TOTAL          1359092
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```
THE SURVEY IS FINISHED.        20 SOLUTIONS HAVE BEEN RETAINED, WITH TOTAL COSTS FROM         1110237  TO         1154743 .
THERE WERE SOME SOLUTIONS FROM          1154743  TO          1210237 ,
BUT IT WAS SPECIFIED NOT TO RETAIN MORE THAN          20  SOLUTIONS.
```

```
FACILITY COMBINATICN RANK     1           TOTAL COST          1110237
              SUMMER DEAD-END . . . . . . . . . . .  1 FELS  2 NFLS  3 PCLS  5 CYLS  6 RSLS  7 WFLS
              ALL-YEAR DEAD-END . . . . . . . . . .  9 FEDL 11 PCDL  7 PDVF
              WINTER STORAGE  . . . . . . . . . . . 24 CYHT 25 RSHT

                                                                  TOTAL FIXED COST          44400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                   SLUDGE DISTRIBUTION PATTERN

                                SOURCE     SOURCE     SOURCE     SOURCE     SOURCE
                        FROM//  1 GMLN     2 PWDH     3 NFLS     4 FFRI     5 PCBN
TO FACILITY  9 FFDL..                0          0          0    2580000          0
TO FACILITY 11 PCDL..                0          0          0          0    3580000
TO FACILITY 17 PDVF..                0   11800000          0          0          0
TO FACILITY 24 CYHT..                0    6363000    7125000    1208000     423000
TO FACILITY 25 RSHT..          3450000          0          0          0          0

                                SOURCE      TOTAL
                        FROM//  6 WLND
TO FACILITY  9 FEDL..                0    2580000
TO FACILITY 11 PCDL..                0    3580000
TO FACILITY 17 PDVF..                0   11800000
TO FACILITY 24 CYHT..          4860000   19979000
TO FACILITY 25 RSHT..                0    3450000

                                                             TOTAL VARIABLE COST          564436
                                                             SYSTEM COST TOTAL SO FAR      608836

SUMMER PORTICN OF SYSTEM

                                   SLUDGE DISTRIBUTION PATTERN

                                SOURCE     SOURCE     SOURCE     SOURCE     SOURCE     SOURCE    STORAGE
                        FROM//  1 GMLN     2 PWDH     3 NFLS     4 FFRI     5 PCBN     6 WLND    24 CYHT
TO FACILITY  1 FELS..                0          0     342000    1208000          0          0          0
TO FACILITY  2 NFLS..                0    6363000    6762000          0          0    2710000          0
TO FACILITY  3 PCLS..                0          0          0          0          0    2150000          0
TO FACILITY  5 CYLS..                0          0      21000          0          0          0   19979000
TO FACILITY  6 RSLS..          3450000          0          0          0          0          0          0
TO FACILITY  7 WFLS..                0          0          0          0     423000          0          0

                               STORAGE      TOTAL
                        FROM// 25 RSHT
TO FACILITY  1 FELS..                0    1550000
TO FACILITY  2 NELS..                0   15835000
TO FACILITY  3 PCLS..                0    2150000
TO FACILITY  5 CYLS..                0   20000000
TO FACILITY  6 RSLS..          3450000    6900000
TO FACILITY  7 WFLS..                0     423000

                                                             TOTAL VARIABLE COST          501401
                                                                  SYSTEM COST TOTAL        1110237
```

```
FACILITY COMBINATION RANK   20          TOTAL COST          1154743
              SUMMER DEAD-END . . . . . . . . . . . 1 FFLS  2 NFLS  3 PCLS  4 PALS  5 CYLS  6 RSLS  7 WFLS
              ALL-YEAR DEAD-END . . . . . . . . . 9 FEDL 17 PDVF
              WINTER STORAGE  . . . . . . . . . . 23 PAHT 24 CYHT

                                                                    TOTAL FIXED COST          44400

WINTER AND ALL-YEAR PORTIONS OF SYSTEM

                                  SLUDGE DISTRIBUTION PATTERN

                               SOURCE      SOURCE      SOURCE      SOURCE      SOURCE
                      FROM//   1 GMLN      2 PWDH      3 NFLS      4 FERI      5 PCBN
TO FACILITY  9 FEDL..              0           0           0    2580000           0
TO FACILITY 17 PDVF..              0    11800000           0          0           0
TO FACILITY 23 PAHT..              0           0           0    1208000     2213000
TO FACILITY 24 CYHT..        3450000     6363000     7125000          0           0

                               SOURCE      TOTAL
                      FROM//   6 WLND
TO FACILITY  9 FEDL..              0     2580000
TO FACILITY 17 PDVF..              0    11800000
TO FACILITY 23 PAHT..              0     3421000
TO FACILITY 24 CYHT..        4860000    21798000
                                                                  TOTAL VARIABLE COST          552948
                                                                  SYSTEM COST TOTAL SO FAR        597348
SUMMER PORTION OF SYSTEM

                                  SLUDGE DISTRIBUTION PATTERN

                               SOURCE      SOURCE      SOURCE      SOURCE      SOURCE      SOURCE      STORAGE
                      FROM//   1 GMLN      2 PWDH      3 NFLS      4 FERI      5 PCBN      6 WLND      23 PAHT
TO FACILITY   1 FFLS..             0           0      342000     1208000           0           0           0
TO FACILITY   2 NFLS..             0     6363000     6783000           0           0     2710000           0
TO FACILITY   3 PCLS..             0           0           0           0           0     2150000           0
TO FACILITY   4 PALS..             0           0           0           0           0           0     3421000
TO FACILITY   5 CYLS..             0           0           0           0           0           0           0
TO FACILITY   6 RSLS..       3450000           0           0           0           0           0           0
TO FACILITY   7 WFLS..             0           0           0           0     2213000           0           0

                               STORAGE     TOTAL
                      FROM//   24 CYHT
TO FACILITY   1 FFLS..             0     1550000
TO FACILITY   2 NFLS..             0    15856000
TO FACILITY   3 PCLS..             0     2150000
TO FACILITY   4 PALS..       1798000     5219000
TO FACILITY   5 CYLS..      20000000    20000000
TO FACILITY   6 RSLS..             0     3450000
TO FACILITY   7 WFLS..             0     2213000

                                                                  TOTAL VARIABLE COST          557396
                                                                        SYSTEM COST TOTAL       1154743
END OF CASE
STATISTICS..        FACSET=       1976      NSTOR=        166      LINCAL=       3566      NOSMMR=          0

END OF ALLO2
```

APPENDIX VIII

TRANSPORT SCHEDULING PROGRAM SCHED1

APPENDIX VIII

TRANSPORT SCHEDULING PROGRAM SCHED1

VIII.1 The Model

A flow network representing the possibilities for material movement is duplicated on each day of the scheduling period. Every transport link in the material distribution network is represented in this scheduling network by one or more parallel links between a source and a sink. Thus, a transfer point or intermediate facility in the distribution network appears here both as a sink and as a source.

The different parallel links between a source and a sink represent the possible assignment of some number of trucks, to do a day's work, from different contractors or truck depots. There is a different cost per truck assigned on each link in order to incorporate the effects of distance from the depot to the haulage task and distance from source to sink. The unit of flow in the scheduling network is the quantity of material that can be moved between two points by one truck in one day. Every truck is assumed to have the same capability in this respect, independent of the point pair or the contractor or depot. However, each contractor or depot can have a different limit in terms of the number of trucks it can supply in one day. In addition, a different fixed charge is added to the total system cost for each contractor or depot. This charge is a linear function of the maximum number of trucks a depot supplies on any one day.

A limit can be put on each source and each sink, on the total number of trucks thay may be assigned on all links connected to it in the same day. This is to prevent an unmanageable number of trucks from arriving in one day at the pick-up dock of a source or the delivery dock of a sink.

On each day in the scheduling network, each sink and each source is represented once.

Every source is linked to itself on consecutive days, representing possible storage of production inventory at its pick-up dock from one day to the next. Every source on the last day is linked to itself on the first day to ensure that its inventory at the end of the period is the same as it was at the beginning. The net output of a source on a day in this network is equal to its gross daily output in the distribution network.

Every sink is linked to itself on consecutive days, representing possible storage of backlog for consumption at its delivery dock from one day to the next. Every sink on the last day is linked to itself on the first day to ensure that its backlog at the end of the period is the same as at the beginning. The net output of a sink on a day in this network is equal to its gross daily input in the distribution network.

The source inventory links and the sink backlog links can be given costs per unit of material assigned to them and limits on the amount of material assigned to them.

Figure 58 illustrates a simple, small scheduling network for three days and two contractors or depots, representing four distribution transport links with three sources and two sinks. Figure 59 illustrates two different distribution networks which the scheduling network in Figure 58 could represent.

VIII.2 The Solution

The optimal schedule is found by a computer program we have written called SCHED1, which consists of about 800 lines of standard FORTRAN IV (USASI or ANSI Fortran)*. This program contains a modified version of W. Domschke's program FLOW1, published recently in the ALGOL language (Domschke, 1973b). The program FLOW1 is designed to find the minimal cost flow in a weighted, antisymmetric directed graph by removing negative cycles found preferably with the first of Domschke's two ALGOL procedures written for this purpose, ZYKL DIJKSTRA or ZYKL FORD, published slightly earlier (Domschke, 1973a). Basically our program SCHED1 uses ZYKL FORD (for reasons explained later) in FLOW1, applying FLOW1 repeatedly to find the minimal cost flow for different given combinations of depot capabilities. Thus, one can find the system that yields the lowest total of the fixed charges due to depot capabilities, plus the minimal cost of flow on the scheduling network, without employing lengthy integer programming techniques that would otherwise be indicated by the fixed charges.

---

* With a WATFIV processor on an IBM 360/75 the program compiles into 31976 bytes of object code.

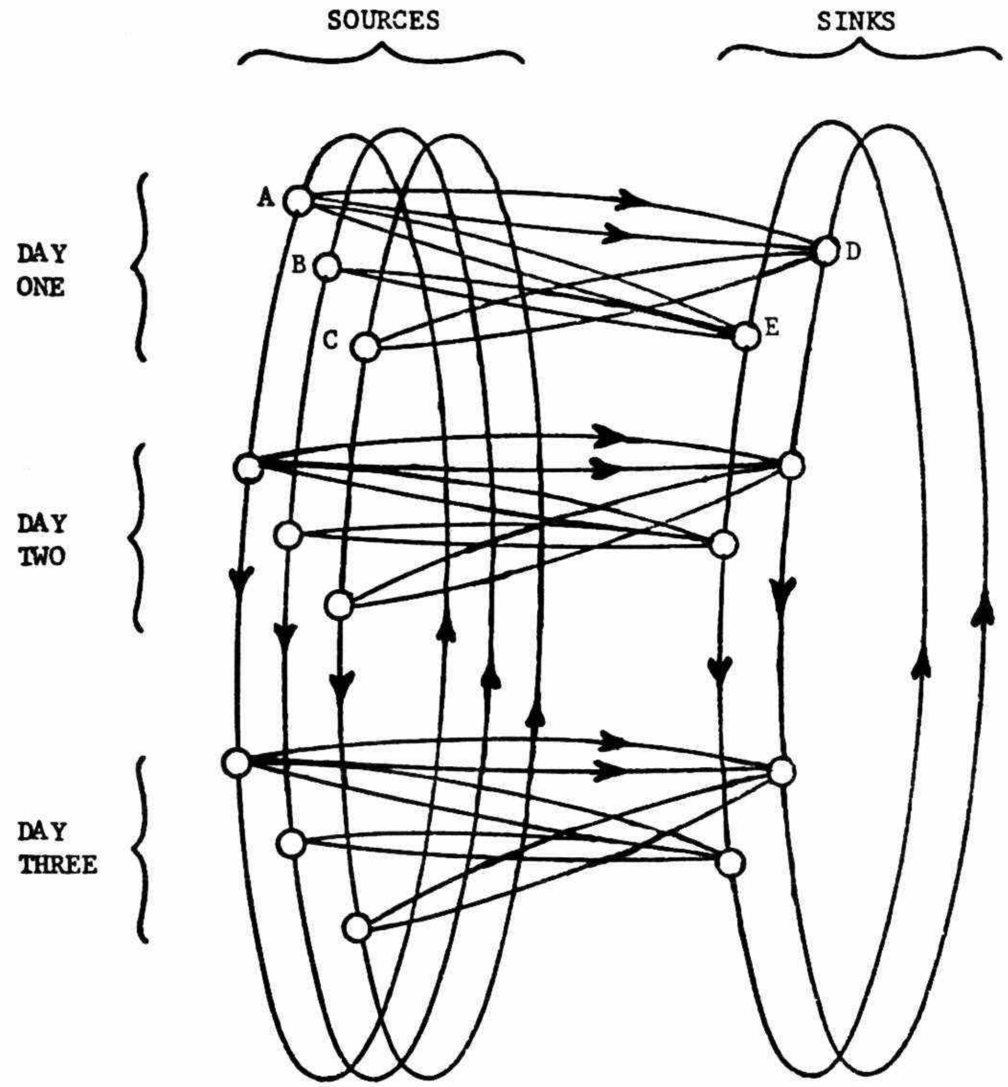


FIGURE 58. SIMPLE SMALL EXAMPLE OF A SCHEDULING NETWORK

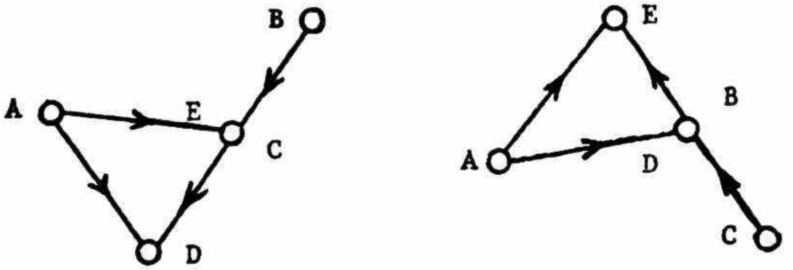


FIGURE 59. POSSIBLE DISTRIBUTION NETWORKS REPRESENTED BY FIGURE 58

Of course, the scheduling network by itself is not antisymmetric; so part of SCHED1 is devoted to adding artifical links to the network to give it this property. SCHED1 also contains a subroutine named SCRIBE that can be called from various points in the program to print out the current antisymmetric network and the total system cost. Whether it is actually called from a particular point depends on indicators put in the data deck by the user.

Since the program works with residual capacity rather than actual flow, the flow pattern in the scheduling network is not immediately obvious from the printout produced by SCRIBE. But it is actually quite simple: every link in the scheduling network is printed out adjacent to its corresponding reverse link in the antisymmetric network, and its flow is just the residual capacity on that reverse link.*

Briefly the main operations of SCHED1 are as follows:

1) Read and write data.
2) Generate a combination of depot capabilities and calculate the resulting sum of fixed charges.
3) Construct the scheduling network and augment it with its reflexive image to produce the required antisymmetric network (this incorporates Step 1 in Part A of FLOW1). Here is "Point 1" for calling SCRIBE.
4) Find an initial solution (FLOW1 Part A, Step 2). "Point 2" for calling Scribe.
5) Find and remove negative cycles using a brute force search, i.e. starting searches at every vertex of the network in order as they are numbered, starting again at the first vertex of the network after doing the last (FLOW1 Part B, Step 1). "Point 3" for calling SCRIBE occurs every time a negative cycle has been removed. This step is not abandoned until a given number of consecutive searches (the number

---

* The program, as presented here, has been tested only on simple hypothetical problems in order to check the correctness of the solution. Modifications to produce a more readable printout would not be difficult and would be a suitable development in conjunction with testing on realistic complex problems made to check the efficiency of the program.

"NH" entered in the data) are unsuccessful in revealing any negative cycle.

6) Find and remove negative cycles using a finer approach, i.e. starting searches at vertices not yet involved in any cycle yet examined (FLOW1 Part B, Step 2). "Point 4" for calling SCRIBE occurs every time a negative cycle has been removed. This step is abandoned when there are no vertices left at which to start a search.
7) Print out final solution if required ("Point 5" for calling SCRIBE). This solution has the minimal cost flow pattern under the given constraints.
   Return to (2) if there are more combinations of depot capabilities; otherwise, stop.

A subroutine named DECAP is integrated with the program in such a way that it can be used to generate all possible combinations of depot capabilities, starting with the capability of all depots summing to one and proceeding to higher total values up to a given limit, simultaneously taking given limits on each depot into account.

For the reader who wishes to undertake further development of the program, rather than use it as it is, we shall now outline its development to date in relation to Domschke's programs.

Our main reference (Domschke, 1973b) actually describes two programs. The first, called FLOW1, is the one we chose to adapt to our purpose. The second involves searches for shortest paths, presumably in an attempt to improve efficiency when working with very large networks; we did not feel the necessity of this more sophisticated approach.

Program FLOW1 treats a completely general antisymmetric network in matrix form. This means that the real flow network is assumed to be already augmented by its reflexive image, which has unit costs assigned to its links equal to the negative of the real unit costs. This also means that every vertex in the network is assumed connected to every other vertex. Moreover, both upper and lower limits on the flow on each link are accommodated.

Since our scheduling network has a very specific sort of structure, with few links compared to the large number possible in an abstract network, we took Domschke's suggestion to arrange all the links in a one-dimensional list rather than in a matrix. This eliminated the problem of introducing flags to indicate matrix elements that were really active; it allowed us to use parallel links between the same pair of vertices; and it eliminated a great deal of computation in the object program for calculating the location of matrix elements in the computer memory.

Thus, we modified FLOW1 to handle vectors instead of matrices; and, following Domschke's suggestion to accompany this modification, we replaced his CYCLE procedure, which is the same as his earlier ZYKL DIJKSTRA procedure, with his ZYKL FORD procedure.

Several other simplifications resulted from the special structure of our scheduling network and the zero lower limit on the flow of each link. Step 1 in Part A of FLOW1 was simplified and incorporated into our routine for constructing the network. Also Step 2 in Part A was shortened and Step 3 was completely omitted. Furthermore, Case 2 Step 1 in Part B does not arise.

However, the CORR procedure in FLOW1 had to be expanded to handle the changes in residual capacities on links which belong to a group of links upon which a total flow limit has been placed. Also, the CYCLE procedure (actually ZYKL FORD) required a minor modification to handle parallel links between the same pair of vertices.

Thus, it can be seen that the amount of development done on SCHED1 is already considerable and the program can be expected to perform very efficiently.

The reader who consults the references should note in passing that the MIN procedure in FLOW1 and the NEGATIV procedure in ZYKL FORD have been changed, in name only, to MINFLO and NEGARC, respectively.

VIII.3 Input Data

The formats for the input data are very elementary. More elaborate formats, including data documentation and alternative modes for input, could be developed quite easily.

The requirements for the data deck are described here in detail. A sample data deck for a three-day schedule with two sources, two sinks and two depots is listed in Table 36.

TABLE 36. DATA DECK FOR SIMPLE SCHED1 EXAMPLE

```
                                                                                   Item No.
                                                                                   in
                                                                                   Description
                                                                                   in Text
    2    2    2    3    2          1000000000 1+10         2     TTTTF             1
    1         6    2        12                                                     2
    1      1+03    2      1+03                                                     3
    1        18    2        24                                                     4
    1        10    2         8                                                     5
    1      2+03    2      2+03                                                     6     Day
    1        20    2        16                                                     7     Type
 1  1    1      1+03    2      1+10                                                8     One
 1  2    1     12+02    2      1+10                                                8
 2  1    1     13+02    2      1+03                                                8
 2  2    1     11+02    2     14+02                                                8
    1        18    2        36                                                     2
    1      3+03    2      3+03                                                     3
    1        10    2        16                                                     4
    1        30    2        24                                                     5
    1      6+03    2      6+03                                                     6     Day
    1        20    2        16                                                     7     Type
 1  1    1      1+03    2      1+10                                                8     Two
 1  2    1     12+02    2      1+10                                                8
 2  1    1     13+02    2      1+03                                                8
 2  2    1     11+02    2     14+02                                                8
                5+02                1+03                8+02                9+02   9
    1        12    2        22                                                     10
    1        22    2        18                                                     11
11211211211211211211211211211211211211211211211211211211211211211211211211211211   12
SPEC                                                                               13
    1        14    2        20                                                     15
    1         0    2        50                                                     15
    1        -1    2         0                                                     15
```

1. The first card in the deck contains the basic structure of the scheduling problem, as well as some parameters for controlling the program:

SRCS: the number of sources in each day of the scheduling network

SNKS: the number of sinks in each day of the scheduling network

DEPS: the number of depots or haulage contractors

DAYS: the number of days in the schedule

DATYPS: the number of "types" of days; different types of days are accommodated with respect to source production and sink consumption, cost coefficients assigned to inventory, backlog and haulage limits, and with respect to the limits on inventory and backlog links. The program will read DATYPS sets of data up to a limit of nine sets for these parameters and assign them to the desired days in the schedule according to a day type sequence entered later in the data.

Z: the largest fixed-point (integer) number the computer can store in a normal storage location; or a smaller integer which is larger than any the program could produce in its computations.

RZ: the largest floating-point (real) number the computer can store in a normal storage location; or, a smaller real which is larger than any the program could produce in its computations.

NH: a parameter which may be varied to optimize the program's efficiency: this is the number of consecutive unsuccessful searches for negative cycles which must occur while starting these searches at each vertex of the scheduling network in order as they are numbered, in order for the program to switch to the routine of selecting vertices at which to start these searches as those vertices not yet involved in any negative cycle. With our simple example (Table 36), which has only twelve vertices, NH=2 has been best. For larger networks, it is conceivable that larger values might be better. Certainly, however, the value must never be more than the total number of vertices in the network.

SCRIBE: a vector of five elements, each given the value T or F (true or false), to indicate whether the program should call subroutine SCRIBE from Points 1, 2, 3, 4, and/or 5 in the program in order to print out the solution.

The format for this data card is: (5I5, I20, E5.0, 5X, 5L1).

The next seven items (2 through 8) are repeated in the data deck once for each day type. The order of these data sets in the deck yields an identifying number for each day type: the first set is for day type #1, the second for day type #2 and so on. These identification numbers are used later when the day type sequence is entered.

2. First, as many cards as necessary, with five sources allowed per card, are used to enter each source's production for the day. This is the net output in the scheduling network, or the gross daily output in the distribution network. Each source must be identified with its production by a number from 1 to SRCS. This identification number precedes each number giving a production value. Each source must have a same identification number in all further data; this number is also used to identify sources in the printout.
Format (5(I5,I10)).

3. As many cards as ncessary, with five sources allowed per card, are used to enter each source's unit cost associated with the network link carrying inventory over the the next day. Each cost coefficient must be preceded by the source's identification number.
Format (5(I5,E10.0)).

4. As many cards as necessary, with five sources allowed per card, are used to enter each source's limit on inventory carried over to the next day. Each limit must be preceded by the source's

identification number.
Format (5(I5,I10)).

5. Next, as many cards as necessary, with five sinks allowed per card, are used to enter each sink's consumption for the day. This is the net input in the scheduling network, or the gross daily input in the distribution network. Each sink must be identified with its consumption by a number from 1 to SNKS. This identification number precedes each number giving a consumption value. Just as for sources, each sink must have the same identification number in all further data and this number is also used in identifying sinks in the printout.
Format (5(I5,I10)).

6. As many cards as necessary, with five sinks allowed per card, are used to enter each sink's unit cost associated with the network link carrying backlog over to the next day. Each cost coefficient must be preceded by the sink's identification number.
Format (5(I5,E10.0)).

7. As many cards as necessary, with five sinks allowed per card, are used to enter each sink's limit on backlog carried over to the next day. Each limit must be preceded by the sink's identification number.
Format (5(I5,I10)).

8. Then, a group of cards numbering SRCS times DEPS times the number of cards used in item 5, 6, or 7, is used to enter the unit costs associated with the haulage links from the sources to the sinks (by means of trucks from the various depots.) For each combination of sources and depots, as many cards as necessary, with five sinks allowed per card, are used to enter the cost per truck-day of delivery to each sink. Identification numbers need not appear on the cards, but the order of the cost coefficients must follow these rules:

a) For each combination of source and depot, the cost coefficients must be entered in order for sinks number 1 to SNKS.

b) For each source, entries must be made in order for depots numbered 1 to DEPS.

c) Entries must be made in order for sources numbered 1 to SRCS. The sample data deck in Table 36, which has the identification numbers entered in "non-data" fields of type X, illustrates this order. We repeat the illustration here for emphasis:

From source 1 using depot 1: unit cost for sink 1, unit cost for sink 2
From source 1 using depot 2: unit cost for sink 1, unit cost for sink 2
From source 2 using depot 1: unit cost for sink 1, unit cost for sink 2
From source 2 using depot 2: unit cost for sink 1, unit cost for sink 2

For combinations of source and sink which are not to be connected, the unit cost must always be entered as the value of RZ. When the program sees this value for a source-sink combination for any depot or any day type, it removes all haulage links for that source-sink combination for all depots and all day types. The format for these cards is: (5X,5(5X,E10.0)).

9. After the data which may depend on day type have all been entered, the coefficients used to calculate the fixed charges assigned to depots are entered on as many cards as necessary, allowing two depots per card. Each depot I is given two coefficients called CFIXA(I) and CFIXB(I); its fixed charge is then calculated, each time it is given a limit on the number of trucks it can supply in one day, as CFIXA(I) plus CFIXB(I) times this limit. The coefficients must be entered in the order CFIXA(1), CFIXB(1), CFIXA (2), CFIXB(2), and so on.
Format (4E20.0).

10. Next, as many cards as necessary, allowing five sources per card, are used to enter the daily limit on the total number of trucks that can visit each source. Each source's limit must be preceded by its identification number.
Format (5(I5,I10)).

11. As many cards as necessary, allowing five sinks per card are used to enter the daily limit on the total number of trucks that can visit each sink. Each sink's limit must be preceded

by its identification number.
Format (5(I5,I10)).

12. Then, as many cards as necessary, allowing 80 days per card, are used to enter the day type sequence. This is just a sequence of numbers, the first number identifying the day type for the first day in the schedule, the second number identifying the day type for the second day in the schedule, and so on. The number of entries is DAYS. In the sample data deck (Table 36) the three-day schedule sequence is repeated the whole length of one card: this was done so that different runs could be made with different values for the parameters DAYS*.
Format (80I1)**.

13. One card is used to direct the mode in which the program generates different combinations of depot capabilities (daily truck limits). By entering the letters "ENUM", you direct the program to generate all possible combinations such that the total capability of all depots is less than or equal to a number NMAX, which is also then entered on this card. Individual upper bounds on each depot, entered on the next card (see Item 14), are also then taken into account. For example, if there are three depots given upper bounds of 2, 1, and 3, respectively, the program will run repeatedly with combinations of depot capabilities in the order shown in Figure 60.

If NMAX is entered as 0 (or blank) or larger than the sum of the upper bounds (here 6), the program changes it to the sum of the upper bounds.

On the other hand, if letters other than "ENUM" are entered, such as "SPEC" then the program would run repeatedly with

---

* For example, by changing DAYS from 3 to 6, a constraint which says the schedule must repeat itself at least every three days is being relaxed to say it must repeat itself at least every 6 days and a more economical schedule should be obtainable. But we pay for a longer schedule with more computing.

** It is this format, which says every day type identification must be a single digit number, that causes the limit of 9 on the value of DATYPS mentioned in Item 1. Of course, other limits are imposed by the dimensions of the array storage space.

Depot 1	Depot 2	Depot 3	NMAX
1	0	0	
0	1	0	
0	0	1	1
2	0	0	
1	1	0	
1	0	1	
0	1	1	
0	0	2	2
2	1	0	
2	0	1	
1	1	1	
1	0	2	
0	1	2	
0	0	3	3
2	1	1	
2	0	2	
1	1	2	
1	0	3	
0	1	3	4
2	1	2	
2	0	3	
1	1	3	5
2	1	3	6

FIGURE 60. ORDER OF ENUMERATION OF DEPOT CAPABILITY COMBINATIONS BY SUBROUTINE DECAP WITH THREE DEPOTS AND UPPER BOUNDS of 2, 1 and 3.

combinations of depot capabilities which you enter in the data (see Item 15). The number NMAX is then meaningless.

The format for this card is: (A4, I6).

14. This item applies only if "ENUM" was entered under Item 13. As many cards as necessary, allowing five depots per card, are used to enter the upper bounds for the capability of each depot, in order to limit the automatic generation of different combinations of depot capabilities. Each upper bound must be preceded by the depot's identification number.

Format (5(I5,I10)).

This would be the end of the data deck if "ENUM" was entered under Item 13.

15. This item applies only if "ENUM" was not entered under Item 13. For each combination of depot capabilities with which you

want the program to run, as many cards as necessary, allowing five depots per card, are used to enter the depot capabilities in the combination. The capability of each depot must be preceded by its identification number.

In order to stop the program neatly (i.e. without incurring an end-of-file error), the last combination should be followed by a dummy combination in which depot number one is given a negative capability. This negative value indicates to the program that it must stop.

Format (5(I5,I10)).

This would be the end of the data deck if "ENUM" was not entered in Item 13.

It may be noted that the sample deck in Table 36 does not have "ENUM" entered but rather the letters "SPEC"; so that the program would read the cards following to obtain the specific combinations of depot capabilities with which it is to run.

Whenever, in the above instructions, it is stated that data associated with certain sources, sinks or depots must be preceded by the source, sink or depot identification number, then the numerical order of the sources etc., need not be followed when entering the data. In fact, the only place where the order is important is in Item 8. However, it is good form to use the obvious numerical order to make sure that no data are omitted.

VIII.4 Limits on Data due to Array Storage Dimensions

This information is provided not only to warn against data that are too large, but also to indicate how the array storage dimensions could be changed to accommodate larger data.

We shall refer to arrays by their symbolic names, as used in the main program. For most of them, this is the same as their names in the subroutines.

For brevity let:

u = number of sources (=SRCS)
v = number of sinks (=SNKS)
w = the larger of u or v

a = number of days (=DAYS)
p = number of depots (=DEPS)
t = number of day types (=DATYPS)
pt= p times t
ap= a times p
n = total number of vertices in scheduling network = a x (u + v)
nl= n + 1
m = twice the total number of links in scheduling network*
$(n + apw \leq \frac{m}{2} \leq n + apuv)$

Then the following list shows the smallest permissible dimensions of the arrays. The arrays are listed in order as they occur in the storage declaration statement in the main program:

R(n), LOC(nl), C(m), SN(m), EN(m);
D(n), DP(n), ST(n), ET(n), PZ(n);
RC(m), DAY(m), DEP(m), RDP(ap), RTL(n);
FD(n), ID(n);
DL(p), DPCP(p), SUM(p), RL(p);
CP(m);
IJ(w), FC(w), ICP(w), ICPR(w), FCR(w), IJR(w);
ISOL(u,v), CPM(u,v,p), SRCTL(u), SNKTL(v), DATP(a), SNKP(v,t), SNKC(v,t), SNKCP(v,t), SRCP(u,t), SRCC(u,t), SRCCP(u,t), TC(u,v,pt), CFIXA(p), CFIXB(p).

Thus, the minimum storage for a problem of a given size can be calculated as:
$uv(1+10a+p+pt) + (u+v)\ (3t+1) + 6p + ap + a + 5w + 7m + 6$,
including the five-element array SCRIB. In addition, 26 elements are required for nonsubscripted variables.**

With the array dimensions shown in the program listing in Table 36 the total number of elements required for variable storage is 16097.

---

* The number of scheduling links is multiplied by 2 to obtain m, which is actually the number of links in the entire antisymmetric network.

** Note that this discussion is in terms of standard elements or "words" of storage which must be multiplied by the appropriate system-dependent factor to get the quantity of storage in terms of bytes or bits. For example, in the IBM 360 system there are 4 bytes or 32 bits per word.

VIII.5 Program Output

The output is best explained by example. The printout obtained by running the data in Table 36 is shown in Table 38. Before we discuss the printout in detail, note first the layout of the data which subroutine SCRIBE produces for each day of the scheduling network. The general form of the layout is shown in Table 37. Each day has three tables: one table for haulage links from sources to sinks and the various depots, each line showing the data for one link and its reciprocal (the reflexive image added for purposes of the algorithm); a second table for inventory links connecting sources to themselves on the next day, each column showing the data for one link and its reciprocal; and a third table for backlog links connecting sinks to themselves on the next day, similar to the table for source inventory links.

In each line or column, the first and last entries (under the heading SRC or SNK) are the identification numbers of the source or sink at the ends of the link. Moreover, in each line for the haulage links the middle entry (under the heading DPO) is the identification number of the depot concerned. Thus, it is easy to tell exactly where each line or column fits into the schedule.

The flow on each link is just the residual capacity of its reciprocal: in each line for haulage links, this is under the heading CP(JR); in each column for inventory and backlog links, this is under the heading CP(RARC).

The other data in these tables are of no interest to the user who is not concerned with the internal mechanism of the program.*

---

* For the record, the significance of the other data is as follows:

ARC or J = the identification number of the link in the entire scheduling network;

RARC or JR = the identification number of the reciprocal link;

NOD = the identification number of the adjacently listed source or sink as a vertex in the entire scheduling network;

CP() = residual capacity of the link identified in the parentheses;

C() = the unit cost assigned to the link in the parentheses;

DEP() = the number identifying both depot and day for the link in the parentheses.

TABLE 37. LAYOUT OF DATA FOR ONE DAY OF THE SCHEDULING NETWORK AS PRODUCED BY SUBROUTINE SCRIBE

Day number

← Headings →
Data on first haulage link; data on reciprocal link
Data on next haulage link; data on reciprocal link
Data on next haulage link; data on reciprocal link
ETC.
.
.
.

↑ Headings ↓	Data on first inventory link; data on reciprocal link	Data on next inventory link; data on reciprocal link	Data on next inventory link; data on reciprocal link	ETC. . .

↑ Headings ↓	Data on first backlog link; data on reciprocal link	Data on next backlog link; data on reciprocal link	Data on next backlog link; data on reciprocal link	ETC. . .

Now, turning to Table 38, the printout is almost self-explanatory. First the input data are printed out, just as they were read in. The headings for this part of the printout are reasonably complete. Since SCRIB = TTTTF in this example, the scheduling network is printed out by subroutine SCRIBE from points 1, 2, 3 and 4, but not 5. Printout from point 5 would be just the same as the last printout from point 4, or from point 3 if point 4 never occurs, or from point 2 if neither point 3 or 4 occurs.** Note that the headings used the term "production" for both source production and sink consumption; and the term "holdover" for both source inventory and sink backlog. Also, the term "daily truck limit" is used for the limits on the total number of trucks that can work out of a source or sink, as well as the limit on the number of trucks that can be supplied by a depot (depot capability).

The data in this example are purely imaginary: they are not intended to be realistic. A total depot capability of 34 trucks would not likely be considered for a system with only two sources and two sinks, and a scheduling period of only three days is unrealistically short. The example is for purposes of illustration only. As to "short" scheduling periods, however, note that each day can actually represent the aggregation of a number of real days.

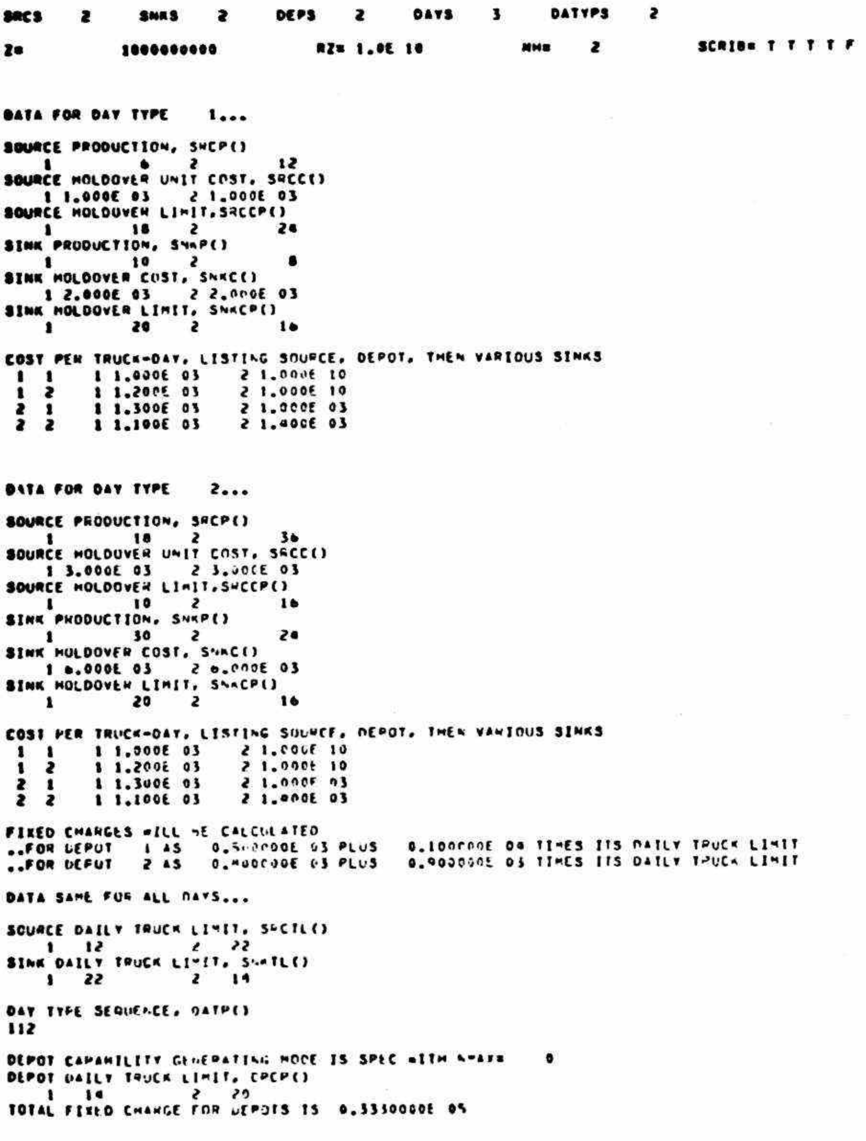
Since the depot capability generating mode is not given as "ENUM" (but as "SPEC"), the program takes the next data as the first set of depot capabilities with which it is to run. This is printed out as "depot daily truck limits" following by total depot fixed charges calculated by the program from these limits.

The output from subroutine SCRIBE then follows. Each time SCRIBE is called, it prints a heading showing the point from which it is called. The first output from SCRIBE is of course from point 1, which is just after the entire antisymmetric network has been set up. All flows

---

** Neither point 2 or 3 or 4 would occur if the constraints were so tight that no solution was possible at any cost: then the program prints out the message "solution infeasible" and goes on to the next set of depot capabilities. If point 2 occurs, then neither point 3 or 4 would occur if the initial solution found by the program had optimal flows on its network links. If point 3 occurs, then point 4 would not occur if the first stage of the search for negative cycles was thorough enough to eliminate the need for the second stage (as in the example shown here).

TABLE 38. PRINTOUT FROM SIMPLE EXAMPLE FOR SCHED1



```
SRCS    2     SNKS    2     DEPS    2     DAYS    3     DATYPS    2

Z=          1000000000          RZ= 1.0E 10          NN=    2          SCRIB= T T T T F


DATA FOR DAY TYPE    1...

SOURCE PRODUCTION, SRCP()
    1        6    2        12
SOURCE HOLDOVER UNIT COST, SRCC()
    1 1.000E 03    2 1.000E 03
SOURCE HOLDOVER LIMIT,SRCCP()
    1       18    2        24
SINK PRODUCTION, SNKP()
    1       10    2         8
SINK HOLDOVER COST, SNKC()
    1 2.000E 03    2 2.000E 03
SINK HOLDOVER LIMIT, SNKCP()
    1       20    2        16

COST PER TRUCK-DAY, LISTING SOURCE, DEPOT, THEN VARIOUS SINKS
 1  1     1 1.000E 03     2 1.000E 10
 1  2     1 1.200E 03     2 1.000E 10
 2  1     1 1.300E 03     2 1.000E 03
 2  2     1 1.100E 03     2 1.400E 03


DATA FOR DAY TYPE    2...

SOURCE PRODUCTION, SRCP()
    1       18    2        36
SOURCE HOLDOVER UNIT COST, SRCC()
    1 3.000E 03    2 3.000E 03
SOURCE HOLDOVER LIMIT,SRCCP()
    1       10    2        16
SINK PRODUCTION, SNKP()
    1       30    2        24
SINK HOLDOVER COST, SNKC()
    1 6.000E 03    2 6.000E 03
SINK HOLDOVER LIMIT, SNKCP()
    1       20    2        16

COST PER TRUCK-DAY, LISTING SOURCE, DEPOT, THEN VARIOUS SINKS
 1  1     1 1.000E 03     2 1.000E 10
 1  2     1 1.200E 03     2 1.000E 10
 2  1     1 1.300E 03     2 1.000E 03
 2  2     1 1.100E 03     2 1.400E 03

FIXED CHARGES WILL BE CALCULATED
..FOR DEPOT    1 AS    0.5000000E 03 PLUS    0.1000000E 04 TIMES ITS DAILY TRUCK LIMIT
..FOR DEPOT    2 AS    0.8000000E 03 PLUS    0.9000000E 03 TIMES ITS DAILY TRUCK LIMIT

DATA SAME FOR ALL DAYS...

SOURCE DAILY TRUCK LIMIT, SRCTL()
    1   12          2   22
SINK DAILY TRUCK LIMIT, SNKTL()
    1   22          2   14

DAY TYPE SEQUENCE, DATP()
112

DEPOT CAPABILITY GENERATING MODE IS SPEC WITH SPARE=     0
DEPOT DAILY TRUCK LIMIT, DPCP()
    1   14          2   20
TOTAL FIXED CHARGE FOR DEPOTS IS  0.3330000E 05
```

```
SCRIBE CALLED FROM POINT 1

DAY  1            SRC NOD ARC,J      C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                   1   7   32     10.00E 02      12       1    1    1        0  1.00E 10      1    1   1
                   1   7   33     12.00E 02      12       2    2    2        0  1.00E 10      2    1   1
                   2   8   36     13.00E 02      14       1    1    1        0  1.00E 10      3    1   1
                   2   8   37     11.00E 02      20       2    2    2        0  1.00E 10      4    1   1
                   2   8   38     10.00E 02      14       1    1    1        0  1.00E 10      7    2   2
                   2   8   39     14.00E 02      18       2    2    2        0  1.00E 10      8    2   2

      SRC           1           2
      NOD           7           8
      ARC          34          40
   C(ARC)  1.00E 03   1.00E 03
  CP(ARC)          15          24
 CP(RARC)           0           0
  C(RARC)  1.00E 10   1.00E 10
     RARC          41          45
      NOD           9          10
      SRC           1           2

                       SNK           1           2
                       NOD           1           2
                       ARC           6          10
                    C(ARC)  2.00E 03   2.00E 03
                   CP(ARC)          20          16
                  CP(RARC)           0           0
                   C(RARC)  1.00E 10   1.00E 10
                      RARC          15          19
                       NOD           3           4
                       SNK           1           2

DAY  2            SRC NOD ARC,J      C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                   1   9   42     10.00E 02      12       3    1    3        0  1.00E 10     11    3   1
                   1   9   43     12.00E 02      12       4    2    4        0  1.00E 10     12    3   1
                   2  10   46     13.00E 02      14       3    1    3        0  1.00E 10     13    3   1
                   2  10   47     11.00E 02      20       4    2    4        0  1.00E 10     14    3   1
                   2  10   48     10.00E 02      14       3    1    3        0  1.00E 10     17    4   2
                   2  10   49     14.00E 02      18       4    2    4        0  1.00E 10     18    4   2

      SRC           1           2
      NOD           9          10
      ARC          44          50
   C(ARC)  1.00E 03   1.00E 03
  CP(ARC)          18          24
 CP(RARC)           0           0
  C(RARC)  1.00E 10   1.00E 10
     RARC          51          55
      NOD          11          12
      SRC           1           2

                       SNK           1           2
                       NOD           3           4
                       ARC          16          20
                    C(ARC)  2.00E 03   2.00E 03
                   CP(ARC)          20          16
                  CP(RARC)           0           0
                   C(RARC)  1.00E 10   1.00E 10
                      RARC          25          29
                       NOD           5           6
                       SNK           1           2

DAY  3            SRC NOD ARC,J      C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                   1  11   52     10.00E 02      12       5    1    5        0  1.00E 10     21    5   1
                   1  11   53     12.00E 02      12       6    2    6        0  1.00E 10     22    5   1
                   2  12   56     13.00E 02      14       5    1    5        0  1.00E 10     23    5   1
                   2  12   57     11.00E 02      20       6    2    6        0  1.00E 10     24    5   1
                   2  12   58     10.00E 02      14       5    1    5        0  1.00E 10     27    6   2
                   2  12   59     14.00E 02      18       6    2    6        0  1.00E 10     28    6   2

      SRC           1           2
      NOD          11          12
      ARC          54          60
   C(ARC)  3.00E 03   3.00E 03
  CP(ARC)          10          16
 CP(RARC)           0           0
  C(RARC)  1.00E 10   1.00E 10
     RARC          31          35
      NOD          13          14
      SRC           1           2

                       SNK           1           2
                       NOD           5           6
                       ARC          26          30
                    C(ARC)  6.00E 03   6.00E 03
                   CP(ARC)          20          16
                  CP(RARC)           0           0
                   C(RARC)  1.00E 10   1.00E 10
                      RARC           5           9
                       NOD           7           8
                       SNK           1           2


 TOTAL NETFLOW COST  0.00000000E-01
   PLUS FIXED COST=  3.55000000E 04
```

```
SCRIBE CALLED FROM POINT 2

DAY  1            SRC NOD ARC,J       C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)    RARC,JR NOD SNK
                    1   7  32      10.00E 09      0        1    1    1         6 -1.00E 03      1     1   1
                    1   7  33      10.00E 09      0        2    2    2         6 -1.20E 03      2     1   1
                    2   8  36      10.00E 09      0        1    1    1         4 -1.30E 03      3     1   1
                    2   8  37      10.00E 09      0        2    2    2         2 -1.10E 03      4     1   1
                    2   8  38      10.00E 09      0        1    1    1         4 -1.00E 03      7     2   2
                    2   8  39      10.00E 09      0        2    2    2        12 -1.40E 03      8     2   2

       SRC           1           2
       NOD           7           8
       ARC          34          40
    C(ARC)  1.00E 03    1.00E 03
   CP(ARC)          18          20
  CP(RARC)           0           4
   C(RARC)  1.00E 10   -1.00E 03
      RARC          41          45
       NOD           9          10
       SRC           1           2

                   SNK           1           2
                   NOD           1           2
                   ARC           6          10
                C(ARC)  2.00E 03    2.00E 03
               CP(ARC)          12           8
              CP(RARC)           8           8
               C(RARC) -2.00E 03   -2.00E 03
                  RARC          15          19
                   NOD           3           4
                   SNK           1           2

DAY  2            SRC NOD ARC,J       C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)    RARC,JR NOD SNK
                    1   9  42      10.00E 09      0        3    1    3         6 -1.00E 03     11     3   1
                    1   9  43      12.00E 02      6        4    2    4         0  1.00E 10     12     3   1
                    2  10  46      10.00E 09      0        3    1    3         4 -1.30E 03     13     3   1
                    2  10  47      11.00E 02      6       .4    2    4         0  1.00E 10     14     3   1
                    2  10  48      10.00E 09      0        3    1    3         4 -1.00E 03     17     4   2
                    2  10  49      14.00E 02      6        4    2    4         8 -1.40E 03     18     4   2

       SRC           1           2
       NOD           9          10
       ARC          44          50
    C(ARC)  1.00E 03    1.00E 03
   CP(ARC)          18          24
  CP(RARC)           0           0
   C(RARC)  1.00E 10    1.00E 10
      RARC          51          55
       NOD          11          12
       SRC           1           2

                   SNK           1           2
                   NOD           3           4
                   ARC          16          20
                C(ARC)  2.00E 03    2.00E 03
               CP(ARC)          12           4
              CP(RARC)           8          12
               C(RARC) -2.00E 03   -2.00E 03
                  RARC          25          29
                   NOD           5           6
                   SNK           1           2

DAY  3.           SRC NOD ARC,J       C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)    RARC,JR NOD SNK
                    1  11  52      10.00E 09      0        5    1    5        12 -1.00E 03     21     5   1
                    1  11  53      10.00E 09      0        6    2    6         0  1.00E 10     22     5   1
                    2  12  56      10.00E 09      0        5    1    5         2 -1.30E 03     23     5   1
                    2  12  57      10.00E 09      0        6    2    6         8 -1.10E 03     24     5   1
                    2  12  58      10.00E 09      0        5    1    5         0  1.00E 10     27     6   2
                    2  12  59      10.00E 09      0        6    2    6        12 -1.40E 03     28     6   2

       SRC           1           2
       NOD          11          12
       ARC          54          60
    C(ARC)  3.00E 03    3.00E 03
   CP(ARC)           4           2
  CP(RARC)           6          14
   C(RARC) -3.00E 03   -3.00E 03
      RARC          31          35
       NOD          13          14
       SRC           1           2

                   SNK           1           2
                   NOD           5           6
                   ARC          26          30
                C(ARC)  6.00E 03    6.00E 03
               CP(ARC)          20          16
              CP(RARC)           0           0
               C(RARC)  1.00E 10    1.00E 10
                  RARC           5           9
                   NOD           7           8
                   SNK           1           2


TOTAL NETFLOW COST  2.4400000E 05
  PLUS FIXED COST=  2.7750000E 05
```

```
SCRIBE CALLED FROM POINT 3

DAY  1            SRC NOD ARC,J      C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)  RARC,JR NOD SNK
                    1   7  32     10.00E 09        0       1   1    1         6 -1.00E 03        1   1   1
                    1   7  33     10.00E 09        0       2   2    2         6 -1.20E 03        2   1   1
                    2   8  36     13.00E 02        4       1   1    1         0  1.00E 10        3   1   1
                    2   8  37     10.00E 09        0       2   2    2         2 -1.10E 03        4   1   1
                    2   8  38     10.00E 09        2       1   1    1         4 -1.00E 03        7   2   2
                    2   8  39     10.00E 09        0       2   2    2        12 -1.40E 03        8   2   2

      SRC            1          2
      NOD            7          8
      ARC           34         40
   C(ARC)  1.00E 03   1.00E 03
  CP(ARC)           19         16
 CP(RARC)            0          8
  C(RARC)  1.00E 10  -1.00E 03
     RARC           41         45
      NOD            9         10
      SRC            1          2

                        SNK            1          2
                        NOD            1          2
                        ARC            6         10
                     C(ARC)   2.00E 03   2.00E 03
                    CP(ARC)           16          8
                   CP(RARC)            4          8
                    C(RARC)  -2.00E 03  -2.00E 03
                       RARC           15         19
                        NOD            3          4
                        SNK            1          2

DAY  2            SRC NOD ARC,J      C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)  RARC,JR NOD SNK
                    1   9  42     10.00E 09        0       3   1    3         6 -1.00E 03       11   3   1
                    1   9  43     12.00E 02        6       4   2    4         0  1.00E 10       12   3   1
                    2  10  46     10.00E 09        0       3   1    3         4 -1.30E 03       13   3   1
                    2  10  47     11.00E 02        2       4   2    4         4 -1.10E 03       14   3   1
                    2  10  48     10.00E 09        0       3   1    3         4 -1.00E 03       17   4   2
                    2  10  49     14.00E 02        2       4   2    4         8 -1.40E 03       18   4   2

      SRC            1          2
      NOD            9         10
      ARC           44         50
   C(ARC)  1.00E 03   1.00E 03
  CP(ARC)           18         24
 CP(RARC)            0          0
  C(RARC)  1.00E 10   1.00E 10
     RARC           51         55
      NOD           11         12
      SRC            1          2

                        SNK            1          2
                        NOD            3          4
                        ARC           16         20
                     C(ARC)   2.00E 03   2.00E 03
                    CP(ARC)           12          4
                   CP(RARC)            8         12
                    C(RARC)  -2.00E 03  -2.00E 03
                       RARC           25         29
                        NOD            5          6
                        SNK            1          2

DAY  3            SRC NOD ARC,J      C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)  RARC,JR NOD SNK
                    1  11  52     10.00E 09        0       5   1    5        12 -1.00E 03       21   5   1
                    1  11  53     10.00E 09        0       6   2    6         0  1.00E 10       22   5   1
                    2  12  56     10.00E 09        0       5   1    5         2 -1.30E 03       23   5   1
                    2  12  57     10.00E 09        0       6   2    6         8 -1.10E 03       24   5   1
                    2  12  58     10.00E 09        0       5   1    5         0  1.00E 10       27   6   2
                    2  12  59     10.00E 09        0       6   2    6        12 -1.40E 03       28   6   2

      SRC            1          2
      NOD           11         12
      ARC           54         60
   C(ARC)  3.00E 03   3.00E 03
  CP(ARC)            4          2
 CP(RARC)            6         14
  C(RARC) -3.00E 03  -3.00E 03
     RARC           31         35
      NOD           13         14
      SRC            1          2

                        SNK            1          2
                        NOD            5          6
                        ARC           26         30
                     C(ARC)   6.00E 03   6.00E 03
                    CP(ARC)           20         16
                   CP(RARC)            8          0
                    C(RARC)   1.00E 10   1.00E 10
                       RARC            5          9
                        NOD            7          8
                        SNK            1          2


TOTAL NETFLOW COST  2.3920000E 05
  PLUS FIXED COST=  2.7250000E 05
```

```
SCRIBE CALLED FROM POINT 1

DAY  1            SRC NOD ARC,J     C(J)       CP(J)  DEP(J) OPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                    1   7  32    10.00E 09       0       1    1    1        6 -1.00E 03      1    1   1
                    1   7  33    10.00E 09       0       2    2    2        6 -1.20E 03      2    1   1
                    2   8  36    13.00E 02       4       1    1    1        0  1.00E 10      3    1   1
                    2   8  37    11.00E 02       2       2    2    2        0  1.00E 10      4    1   1
                    2   8  38    10.00E 09       2       1    1    1        4 -1.00E 03      7    2   2
                    2   8  39    10.00E 09       2       2    2    2       12 -1.40E 03      8    2   2
      SRC               1           2
      NOD               7           8
      ARC              34          40
   C(ARC)  1.00E 03  1.00E 03
  CP(ARC)              19          14
 CP(RARC)               0          10
  C(RARC)  1.00E 10 -1.00E 03
     RARC              41          45
      NOD               9          10
      SRC               1           2

                      SNK               1           2
                      NGD               1           2
                      ARC               6          10
                   C(ARC)  2.00E 03  2.00E 03
                  CP(ARC)              18           6
                 CP(RARC)               2           8
                  C(RARC) -2.00E 03 -2.00E 03
                     RARC              15          19
                      NGD               3           4
                      SNK               1           2
DAY  2            SRC NOD ARC,J     C(J)       CP(J)  DEP(J) OPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                    1   9  42    10.00E 09       0       3    1    3        6 -1.00E 03     11    3   1
                    1   9  43    12.00E 02       6       4    2    4        0  1.00E 10     12    3   1
                    2  10  46    10.00E 09       0       3    1    3        4 -1.50E 03     13    3   1
                    2  10  47    10.00E 09       0       4    2    4        6 -1.10E 03     14    3   1
                    2  10  48    10.00E 09       0       3    1    3        4 -1.00E 03     17    4   2
                    2  10  49    10.00E 09       0       4    2    4        8 -1.40E 03     18    4   2
      SRC               1           2
      NOD               9          10
      ARC              44          50
   C(ARC)  1.00E 03  1.00E 03
  CP(ARC)              18          24
 CP(RARC)               0           0
  C(RARC)  1.00E 10  1.00E 10
     RARC              51          55
      NOD              11          12
      SRC               1           2

                      SNK               1           2
                      NGD               3           4
                      ARC              16          20
                   C(ARC)  2.00E 03  2.00E 03
                  CP(ARC)              12           4
                 CP(RARC)               8          12
                  C(RARC) -2.00E 03 -2.00E 03
                     RARC              25          29
                      NGD               5           6
                      SNK               1           2
DAY  3            SRC NOD ARC,J     C(J)       CP(J)  DEP(J) OPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                    1  11  52    10.00E 09       0       5    1    5       12 -1.00E 03     21    5   1
                    1  11  53    10.00E 09       0       6    2    6        0  1.00E 10     22    5   1
                    2  12  56    10.00E 09       0       5    1    5        2 -1.30E 03     23    5   1
                    2  12  57    10.00E 09       0       6    2    6        8 -1.10E 03     24    5   1
                    2  12  58    10.00E 09       0       5    1    5        0  1.00E 10     27    6   2
                    2  12  59    10.00E 09       0       6    2    6       12 -1.40E 03     28    6   2
      SRC               1           2
      NOD              11          12
      ARC              54          60
   C(ARC)  3.00E 03  3.00E 03
  CP(ARC)               4           2
 CP(RARC)               6          14
  C(RARC) -3.00E 03 -3.00E 03
     RARC              31          35
      NOD              13          14
      SRC               1           2

                      SNK               1           2
                      NGD               5           6
                      ARC              26          30
                   C(ARC)  6.00E 03  6.00E 03
                  CP(ARC)              20          16
                 CP(RARC)               0           0
                  C(RARC)  1.00E 10  1.00E 10
                     RARC               5           9
                      NGD               7           8
                      SNK               1           2

TOTAL NETFLOW COST  2.37200000E 05
  PLUS FIXED COSTS  2.30500000E 05
```

```
SCRIBE CALLED FROM POINT 3

DAY  1            SRC NOD ARC,J      C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                    1   7  32     10.00E 09       2       1    1    1         6 -1.00E 03       1   1   1
                    1   7  33     12.00E 02       2       2    2    2         4 -1.20E 03       2   1   1
                    2   8  36     13.00E 02       4       1    1    1         0  1.00E 10       3   1   1
                    2   8  37     11.00E 02       4       2    2    2         8  1.00E 10       4   1   1
                    2   8  38     10.00E 09       2       1    1    1         4 -1.00E 03       7   2   2
                    2   8  39     10.00E 09       2       2    2    2        12 -1.40E 03       8   2   2

     SRC          1           2
     NOD          7           8
     ARC         34          40
  C(ARC)  1.00E 03   1.00E 03
 CP(ARC)         16          14
CP(RARC)          2          10
 C(RARC) -1.00E 03  -1.00E 03
    RARC         41          45
     NOD          9          10
     SRC          1           2

                     SNK          1           2
                     NOD          1           2
                     ARC          6          10
                  C(ARC)  2.00E 03   2.00E 03
                 CP(ARC)         20           8
                CP(RARC)          0           8
                 C(RARC)  1.00E 10  -2.00E 03
                    RARC         15          19
                     NOD          3           4
                     SNK          1           2

DAY  2            SRC NOD ARC,J      C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                    1   9  42     10.00E 09       0       3    1    3         6 -1.00E 03      11   3   1
                    1   9  43     12.00E 02       4       4    2    4         2 -1.20E 03      12   3   1
                    2  10  46     10.00E 09       0       3    1    3         4 -1.30E 03      13   3   1
                    2  10  47     10.00E 09       0       4    2    4         6 -1.10E 03      14   3   1
                    2  10  48     10.00E 09       0       3    1    3         4 -1.00E 03      17   4   2
                    2  10  49     10.00E 09       0       4    2    4         8 -1.40E 03      18   4   2

     SRC          1           2
     NOD          9          10
     ARC         44          50
  C(ARC)  1.00E 03   1.00E 03
 CP(ARC)         18          24
CP(RARC)          0           0
 C(RARC)  1.00E 10   1.00E 10
    RARC         51          55
     NOD         11          12
     SRC          1           2

                     SNK          1           2
                     NOD          3           4
                     ARC         16          20
                  C(ARC)  2.00E 03   2.00E 03
                 CP(ARC)         12           4
                CP(RARC)          8          12
                 C(RARC) -2.00E 03  -2.00E 03
                    RARC         25          29
                     NOD          5           6
                     SNK          1           2

DAY  3            SRC NOD ARC,J      C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                    1  11  52     10.00E 09       0       5    1    5        12 -1.00E 03      21   5   1
                    1  11  53     10.00E 09       0       6    2    6         0  1.00E 10      22   5   1
                    2  12  56     10.00E 09       0       5    1    5         2 -1.30E 03      23   5   1
                    2  12  57     10.00E 09       0       6    2    6         8 -1.10E 03      24   5   1
                    2  12  58     10.00E 09       0       5    1    5         0  1.00E 10      27   6   2
                    2  12  59     10.00E 09       0       6    2    6        12 -1.40E 03      28   6   2

     SRC          1           2
     NOD         11          12
     ARC         54          60
  C(ARC)  3.00E 03   3.00E 03
 CP(ARC)          4           2
CP(RARC)          6          14
 C(RARC) -3.00E 03  -3.00E 03
    RARC         31          35
     NOD         13          14
     SRC          1           2

                     SNK          1           2
                     NOD          5           6
                     ARC         26          30
                  C(ARC)  6.00E 03   6.00E 03
                 CP(ARC)         20          16
                CP(RARC)          0           0
                 C(RARC)  1.00E 10   1.00E 10
                    RARC          5           9
                     NOD          7           8
                     SNK          1           2


  TOTAL NETFLOW COST  2.4520000E 05
    PLUS FIXED COST=  2.6450000E 05
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SCHIRE CALLED FROM POINT 3

DAY  1          SRC NOD ARC,J      C(J)      CP(J)  DEP(J) DPO DEP(JR) CP(JR)    C(JR)   RARC,JR NOD SNK
                  1   7   32    10.00E 09       4       1   1   1          6 -1.00E 03      1    1   1
                  1   7   33    12.00E 02       6       2   2   2          0  1.00E 10      2    1   1
                  2   8   36    13.00E 02       2       1   1   1          0  1.00E 10      3    1   1
                  2   8   37    11.00E 02       2       2   2   2          4 -1.10E 03      4    1   1
                  2   8   38    10.00E 09       2       1   1   1          4 -1.00E 03      7    2   2
                  2   8   39    10.00E 09       2       2   2   2         12 -1.40E 03      8    2   2

      SRC          1          2
      NOD          7          8
      ARC         34         40
   C(ARC)  1.00E 03   1.00E 03
  CP(ARC)         12         18
 CP(RARC)          6          6
  C(RARC) -1.00E 03  -1.00E 03
     RARC         41         45
      NOD          9         10
      SRC          1          2

                  SNK          1          2
                  NOD          1          2
                  ARC          6         10
               C(ARC)   2.00E 03   2.00E 03
              CP(ARC)         20          8
             CP(RARC)          0          8
              C(RARC)   1.00E 10  -2.00E 03
                 RARC         15         19
                  NOD          3          4
                  SNK          1          2

DAY  2          SRC NOD ARC,J      C(J)      CP(J)  DEP(J) DPO DEP(JR) CP(JR)    C(JR)   RARC,JR NOD SNK
                  1   9   42    10.00E 09       0       3   1   3          6 -1.00E 03     11    3   1
                  1   9   43    10.00E 09       0       4   2   4          6 -1.20E 03     12    3   1
                  2  10   46    13.00E 02       4       3   1   3          8  1.00E 10     13    3   1
                  2  10   47    10.00E 09       0       4   2   4          6 -1.10E 03     14    3   1
                  2  10   48    10.00E 09       4       3   1   3          4 -1.00E 03     17    4   2
                  2  10   49    10.00E 09       0       4   2   4          8 -1.40E 03     18    4   2

      SRC          1          2
      NOD          9         10
      ARC         44         50
   C(ARC)  1.00E 03   1.00E 03
  CP(ARC)         18         24
 CP(RARC)          0          0
  C(RARC)  1.00E 10   1.00E 10
     RARC         51         55
      NOD         11         12
      SRC          1          2

                  SNK          1          2
                  NOD          3          4
                  ARC         16         20
               C(ARC)   2.00E 03   2.00E 03
              CP(ARC)         12          4
             CP(RARC)          8         12
              C(RARC)  -2.00E 03  -2.00E 03
                 RARC         25         29
                  NOD          5          6
                  SNK          1          2

DAY  3          SRC NOD ARC,J      C(J)      CP(J)  DEP(J) DPO DEP(JR) CP(JR)    C(JR)   RARC,JR NOD SNK
                  1  11   52    10.00E 09       0       5   1   5         12 -1.00E 03     21    5   1
                  1  11   53    10.00E 09       0       6   2   6          0  1.00E 10     22    5   1
                  2  12   56    10.00E 09       0       5   1   5          2 -1.30E 03     23    5   1
                  2  12   57    10.00E 09       0       6   2   6          8 -1.10E 03     24    5   1
                  2  12   55    10.00E 09       0       5   1   5          8  1.00E 10     27    6   2
                  2  12   59    10.00E 09       0       6   2   6         12 -1.40E 03     28    6   2

      SRC          1          2
      NOD         11         12
      ARC         54         60
   C(ARC)  3.00E 03   3.00E 03
  CP(ARC)          4          2
 CP(RARC)          6         14
  C(RARC) -3.00E 03  -3.00E 03
     RARC         31         35
      NOD         13         14
      SRC          1          2

                  SNK          1          2
                  NOD          5          6
                  ARC         26         30
               C(ARC)   6.00E 03   6.00E 03
              CP(ARC)         20         16
             CP(RARC)          0          0
              C(RARC)   1.00E 10   1.00E 10
                 RARC          5          9
                  NOD          7          8
                  SNK          1          2


TOTAL NETFLOW COST  2.388[illegible] 05
  PLUS FIXED COSTS  2.477[illegible] 05
DEPOT DAILY TRUCK LIMIT, (TRUCK)
   1    9          2   59
TOTAL FIXED CHANGE FOR DEPOTS IS  [illegible] 05
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SCRIBE CALLED FROM POINT 1

DAY  1          SRC NOD ARC,J     C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                  1   7  32     10.00E 02       0       1    1    1         0  1.00E 10       1     1   1
                  1   7  33     12.00E 02      12       2    2    2         0  1.00E 10       2     1   1
                  2   8  36     13.00E 02       0       1    1    1         0  1.00E 10       3     1   1
                  2   8  37     11.00E 02      22       2    2    2         0  1.00E 10       4     1   1
                  2   8  38     10.00E 02       0       1    1    1         0  1.00E 10       7     2   2
                  2   8  39     14.00E 02      18       2    2    2         0  1.00E 10       8     2   2

      SRC          1           2
      NOD          7           8
      ARC         34          40
   C(ARC)  1.00E 03   1.00E 03
  CP(ARC)         18          24
 CP(RARC)          0           0
  C(RARC)  1.00E 10   1.00E 10
     RARC         41          45
      NOD          9          10
      SRC          1           2

                         SNK          1           2
                         NOD          1           2
                         ARC          6          10
                      C(ARC)  2.00E 03   2.00E 03
                     CP(ARC)         20          16
                    CP(RARC)          0           0
                     C(RARC)  1.00E 10   1.00E 10
                        RARC         15          19
                         NOD          3           4
                         SNK          1           2

DAY  2          SRC NOD ARC,J     C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                  1   9  42     10.00E 02       0       3    1    3         0  1.00E 10      11     3   1
                  1   9  43     12.00E 02      12       4    2    4         0  1.00E 10      12     3   1
                  2  10  46     13.00E 02       0       3    1    3         0  1.00E 10      13     3   1
                  2  10  47     11.00E 02      22       4    2    4         0  1.00E 10      14     3   1
                  2  10  48     10.00E 02       0       3    1    3         0  1.00E 10      17     4   2
                  2  10  49     14.00E 02      18       4    2    4         0  1.00E 10      18     4   2

      SRC          1           2
      NOD          9          10
      ARC         44          50
   C(ARC)  1.00E 03   1.00E 03
  CP(ARC)         18          24
 CP(RARC)          0           0
  C(RARC)  1.00E 10   1.00E 10
     RARC         51          55
      NOD         11          12
      SRC          1           2

                         SNK          1           2
                         NOD          3           4
                         ARC         16          20
                      C(ARC)  2.00E 03   2.00E 03
                     CP(ARC)         20          16
                    CP(RARC)          0           0
                     C(RARC)  1.00E 10   1.00E 10
                        RARC         25          29
                         NOD          5           6
                         SNK          1           2

DAY  3          SRC NOD ARC,J     C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                  1  11  52     10.00E 02       0       5    1    5         0  1.00E 10      21     5   1
                  1  11  53     12.00E 02      12       6    2    6         0  1.00E 10      22     5   1
                  2  12  56     13.00E 02       0       5    1    5         0  1.00E 10      23     5   1
                  2  12  57     11.00E 02      22       6    2    6         0  1.00E 10      24     5   1
                  2  12  58     10.00E 02       0       5    1    5         0  1.00E 10      27     6   2
                  2  12  59     14.00E 02      18       6    2    6         0  1.00E 10      28     6   2

      SRC          1           2
      NOD         11          12
      ARC         54          60
   C(ARC)  3.00E 03   3.00E 03
  CP(ARC)         10          16
 CP(RARC)          0           0
  C(RARC)  1.00E 10   1.00E 10
     RARC         31          35
      NOD         13          14
      SRC          1           2

                         SNK          1           2
                         NOD          5           6
                         ARC         26          30
                      C(ARC)  6.00E 03   6.00E 03
                     CP(ARC)         20          16
                    CP(RARC)          0           0
                     C(RARC)  1.00E 10   1.00E 10
                        RARC          5           9
                         NOD          7           8
                         SNK          1           2


 TOTAL NETFLOW COST  0.00000000E-01
   PLUS FIXED COST=  4.83000000E 04
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SCRIBE CALLED FROM POINT 2

DAY  1           SRC NOD ARC,J       C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                   1   7  32     10.00E 09        0       1    1    1         0 -1.00E 03        1   1   1
                   1   7  33     10.00E 09        0       2    2    2        12 -1.20E 03        2   1   1
                   2   8  36     10.00E 09        0       1    1    1         0  1.00E 10        3   1   1
                   2   8  37     10.00E 09        0       2    2    2         6 -1.10E 03        4   1   1
                   2   8  38     10.00E 09        0       1    1    1         0  1.00E 10        7   2   2
                   2   8  39     10.00E 09        0       2    2    2        16 -1.40E 03        8   2   2

      SRC            1           2
      NOD            7           8
      ARC           34          40
   C(ARC)  1.00E 03   1.00E 03
  CP(ARC)           18          20
 CP(RARC)            0           4
  C(RARC)  1.00E 10  -1.00E 03
     RARC           41          45
      NOD            9          10
      SRC            1           2

                           SNK            1           2
                           NGD            1           2
                           ARC            6          10
                        C(ARC)   2.00E 03    2.00E 03
                       CP(ARC)           12           8
                      CP(RARC)            8           8
                       C(RARC)  -2.00E 03   -2.00E 03
                          RARC           15          19
                           NGD            3           4
                           SNK            1           2

DAY  2           SRC NOD ARC,J       C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                   1   9  42     10.00E 09        0       3    1    3         0 -1.00E 03       11   3   1
                   1   9  43     12.00E 02        6       4    2    4         6 -1.20E 03       12   3   1
                   2  10  46     10.00E 09        0       3    1    3         0  1.00E 10       13   3   1
                   2  10  47     11.00E 02        6       4    2    4         4 -1.10E 03       14   3   1
                   2  10  48     10.00E 09        0       3    1    3         0  1.00E 10       17   4   2
                   2  10  49     14.00E 02        6       4    2    4        12 -1.40E 03       18   4   2

      SRC            1           2
      NOD            9          10
      ARC           48          50
   C(ARC)  1.00E 03   1.00E 03
  CP(ARC)           18          24
 CP(RARC)            0           0
  C(RARC)  1.00E 10   1.00E 10
     RARC           51          55
      NOD           11          12
      SRC            1           2

                           SNK            1           2
                           NGD            3           4
                           ARC           16          20
                        C(ARC)   2.00E 03    2.00E 03
                       CP(ARC)           12           4
                      CP(RARC)            8          12
                       C(RARC)  -2.00E 03   -2.00E 03
                          RARC           25          29
                           NGD            5           6
                           SNK            1           2

DAY  3           SRC NOD ARC,J       C(J)       CP(J)  DEP(J) DPO DEP(JR) CP(JR)     C(JR)   RARC,JR NOD SNK
                   1  11  52     10.00E 09        0       5    1    5         0 -1.00E 03       21   5   1
                   1  11  53     10.00E 09        0       6    2    6        12 -1.20E 03       22   5   1
                   2  12  56     10.00E 09        0       5    1    5         0  1.00E 10       23   5   1
                   2  12  57     10.00E 09        0       6    2    6        10 -1.10E 03       24   5   1
                   2  12  58     10.00E 09        0       5    1    5         0  1.00E 10       27   6   2
                   2  12  59     10.00E 09        0       6    2    6        12 -1.40E 03       28   6   2

      SRC            1           2
      NOD           11          12
      ARC           54          60
   C(ARC)  3.00E 03   3.00E 03
  CP(ARC)            4           2
 CP(RARC)            6          14
  C(RARC) -3.00E 03  -3.00E 03
     RARC           31          35
      NOD           13          14
      SRC            1           2

                           SNK            1           2
                           NGD            5           6
                           ARC           26          30
                        C(ARC)   6.00E 03    6.00E 03
                       CP(ARC)           20          16
                      CP(RARC)            0           0
                       C(RARC)   1.00E 10    1.00E 10
                          RARC            5           9
                           NGD            7           8
                           SNK            1           2


TOTAL NETFLOW COST  2.5000000E 05
  PLUS FIXED COST=  2.9630000E 05
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SCRIBE CALLED FROM POINT 3

DAY  1              SRC NOD ARC,J      C(J)        CP(J)  DEP(J) DPO DEP(JR) CP(JR)      C(JR)   RARC,JR NOD SNK
                      1   7  32     10.00E 09         0        1   1   1          0 -1.00E 03        1   1   1
                      1   7  33     10.00E 09         0        2   2   2         12 -1.20E 03        2   1   1
                      2   8  36     10.00E 09         0        1   1   1          0  1.00E 10        3   1   1
                      2   8  37     11.00E 02         6        2   2   2          0  1.00E 10        4   1   1
                      2   8  38     10.00E 09         0        1   1   1          0  1.00E 10        7   2   2
                      2   8  39     10.00E 09         2        2   2   2         16 -1.40E 03        8   2   2

      SRC           1           2
      NOD           7           8
      ARC          34          40
   C(ARC)  1.00E 03  1.00E 03
  CP(ARC)          18          14
 CP(RARC)           0          10
  C(RARC)  1.00E 10 -1.00E 03
     RARC          41          45
      NOD           9          10
      SRC           1           2

                         SNK           1           2
                         NGD           1           2
                         ARC           6          10
                      C(ARC)   2.00E 03  2.00E 03
                     CP(ARC)          18           8
                    CP(RARC)           2           8
                     C(RARC)  -2.00E 03 -2.00E 03
                        RARC          15          19
                         NGD           3           4
                         SNK           1           2

DAY  2              SRC NOD ARC,J      C(J)        CP(J)  DEP(J) DPO DEP(JR) CP(JR)      C(JR)   RARC,JR NOD SNK
                      1   9  42     10.00E 09         0        3   1   3          0 -1.00E 03       11   3   1
                      1   9  43     12.00E 02         6        4   2   4          6 -1.20E 03       12   3   1
                      2  10  46     10.00E 09         0        3   1   3          0  1.00E 10       13   3   1
                      2  10  47     10.00E 09         0        4   2   4         10 -1.10E 03       14   3   1
                      2  10  48     10.00E 09         0        3   1   3          0  1.00E 10       17   4   2
                      2  10  49     10.00E 09         0        4   2   4         12 -1.40E 03       18   4   2

      SRC           1           2
      NOD           9          10
      ARC          44          50
   C(ARC)  1.00E 03  1.00E 03
  CP(ARC)          16          24
 CP(RARC)           0           0
  C(RARC)  1.00E 10  1.00E 10
     RARC          51          55
      NOD          11          12
      SRC           1           2

                         SNK           1           2
                         NGD           3           4
                         ARC          16          20
                      C(ARC)   2.00E 03  2.00E 03
                     CP(ARC)          12           4
                    CP(RARC)           8          12
                     C(RARC)  -2.00E 03 -2.00E 03
                        RARC          25          29
                         NGD           5           6
                         SNK           1           2

DAY  3              SRC NOD ARC,J      C(J)        CP(J)  DEP(J) DPO DEP(JR) CP(JR)      C(JR)   RARC,JR NOD SNK
                      1  11  52     10.00E 09         0        5   1   5          0 -1.00E 03       21   5   1
                      1  11  53     10.00E 09         0        6   2   6         12 -1.20E 03       22   5   1
                      2  12  56     10.00E 09         0        5   1   5          0  1.00E 10       23   5   1
                      2  12  57     10.00E 09         0        6   2   6         10 -1.10E 03       24   5   1
                      2  12  58     10.00E 09         0        5   1   5          0  1.00E 10       27   6   2
                      2  12  59     10.00E 09         0        6   2   6         12 -1.40E 03       28   6   2

      SRC           1           2
      NOD          11          12
      ARC          54          60
   C(ARC)  3.00E 03  3.00E 03
  CP(ARC)           4           2
 CP(RARC)           6          14
  C(RARC) -3.00E 03 -3.00E 03
     RARC          31          35
      NOD          13          14
      SRC           1           2

                         SNK           1           2
                         NGD           5           6
                         ARC          26          30
                      C(ARC)   6.00E 03  6.00E 03
                     CP(ARC)          20          16
                    CP(RARC)           0           0
                     C(RARC)   1.00E 10  1.00E 10
                        RARC           5           9
                         NGD           7           8
                         SNK           1           2


TOTAL NETFLOW COST  2.4400000E 05
  PLUS FIXED COST=  2.4010000E 05
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SCHICC CALLED FROM POINT 3

DAY 1              SRC NOD ARC,J      C(J)        CP(J)  DEP(J) DPO DEP(JR) CP(JR)      C(JR)   RARC,JR NOD SNK
                     1   7  32     10.00E 09        0       1    1    1       0 -1.00E 03       1     1   1
                     1   7  33     12.00E 02        2       2    2    2      10 -1.20E 03       2     1   1
                     2   8  36     10.00E 09        0       1    1    1       0  1.00E 10       3     1   1
                     2   8  37     11.00E 02        6       2    2    2       2  1.00E 10       4     1   1
                     2   8  38     10.00E 09        0       1    1    1       0  1.00E 10       7     2   2
                     2   8  39     10.00E 09        2       2    2    2      16 -1.40E 03       8     2   2

      SRC          1            2
      NOD          7            8
      ARC         34           40
  C(ARC)   1.00E 03    1.00E 03
 CP(ARC)          16           14
CP(RARC)           2           10
 C(RARC)  -1.00E 03   -1.00E 03
     RARC         41           45
      NOD          9           10
      SRC          1            2

                     SNK           1            2
                     NOD           1            2
                     ARC           6           10
                 C(ARC)    2.00E 03    2.00E 03
                CP(ARC)           20            8
               CP(RARC)            0            8
                C(RARC)    1.00E 10   -2.00E 03
                    RARC          15           19
                     NOD           3            4
                     SNK           1            2

DAY 2              SRC NOD ARC,J      C(J)        CP(J)  DEP(J) DPO DEP(JR) CP(JR)      C(JR)   RARC,JR NOD SNK
                     1   9  42     10.00E 09        0       3    1    3       0 -1.00E 03      11     3   1
                     1   9  43     12.00E 02        4       4    2    4       8 -1.20E 03      12     3   1
                     2  10  46     10.00E 09        0       3    1    3       0  1.00E 10      13     3   1
                     2  10  47     10.00E 09        0       4    2    4      10 -1.10E 03      14     3   1
                     2  10  48     10.00E 09        0       3    1    3       0  1.00E 10      17     4   2
                     2  10  49     10.00E 09        0       4    2    4      12 -1.40E 03      18     4   2

      SRC          1            2
      NOD          9           10
      ARC         44           50
  C(ARC)   1.00E 03    1.00E 03
 CP(ARC)          18           24
CP(RARC)           0            0
 C(RARC)   1.00E 10    1.00E 10
     RARC         51           55
      NOD         11           12
      SRC          1            2

                     SNK           1            2
                     NOD           3            4
                     ARC          16           20
                 C(ARC)    2.00E 03    2.00E 03
                CP(ARC)           12            4
               CP(RARC)            8           12
                C(RARC)   -2.00E 03   -2.00E 03
                    RARC          25           29
                     NOD           5            6
                     SNK           1            2

DAY 3              SRC NOD ARC,J      C(J)        CP(J)  DEP(J) DPO DEP(JR) CP(JR)      C(JR)   RARC,JR NOD SNK
                     1  11  52     10.00E 09        0       5    1    5       0 -1.00E 03      21     5   1
                     1  11  53     10.00E 09        0       6    2    6      12 -1.20E 03      22     5   1
                     2  12  56     10.00E 09        0       5    1    5       0  1.00E 10      23     5   1
                     2  12  57     10.00E 09        0       6    2    6      10 -1.10E 03      24     5   1
                     2  12  58     10.00E 09        0       5    1    5       0  1.00E 10      27     6   2
                     2  12  59     10.00E 09        0       6    2    6      12 -1.40E 03      28     6   2

      SRC          1            2
      NOD         11           12
      ARC         54           60
  C(ARC)   3.00E 03    3.00E 03
 CP(ARC)           4            2
CP(RARC)           6           14
 C(RARC)  -3.00E 03   -3.00E 03
     RARC         31           35
      NOD         13           14
      SRC          1            2

                     SNK           1            2
                     NOD           5            6
                     ARC          26           30
                 C(ARC)    5.00E 03    6.00E 03
                CP(ARC)           20           16
               CP(RARC)            0            0
                C(RARC)    1.00E 10    1.00E 10
                    RARC           5            9
                     NOD           7            8
                     SNK           1            2

TOTAL NETFLOW COST  2.2200000E 05
  PLUS FIXED COST=  2.8830000E 05
```

are zero, as can be seen under the headings CP(JR) and CP(RARC); so the total cost calculated by SCRIBE from the scheduled flows is zero, as can be seen at the end of this schedule beside the heading "total netflow cost." The total system cost at this point, following the heading "total netflow cost plus fixed cost" is just the total fixed cost.

Note that there are no haulage links from source 1 to sink 2 as the unit cost for these was entered equal to RZ.

The SCRIBE printout from point 2 is next, just after an initial solution has been found. This schedule has flows on its links such that all production/consumption requirements and all truck and holdover limits are satisfied. From this point, the program enters the first stage of the search for negative cycles in an attempt to reduce the total cost of these flows.

Four negative cycles were found in this stage of the search, as can be seen from the fact that SCRIBE was called from point 3 four times. Each of these printouts by SCRIBE shows a reduced total cost of scheduled flows. The last of these printouts is followed immediately by a new set of depot capabilities printed out by the main program. Since the indicator SCRIB asked for printout from 4, it is apparent that no further improvement was possible on the solution shown in the last printout from point 3. That is, the second stage of the search for negative cycles revealed no such cycles, point 4 never occurred, and since SCRIB did not ask for printout of the final solution (from point 5), the program went directly on to start again with the next set of depot capabilities, which it read from the data.

The second set of depot capabilities eliminates the use of one of the depots by giving it zero capability. The capability of the other depot is raised enough so that its own limit is not an active constraint. The purpose of trying such a set of depot capabilities would be to see if two depots were really needed if one could be made as large as desired.

This time SCRIBE was called from points 1 and 2 just twice from point 3; again, point 4 did not occur. The last solution printed out is not followed by a new set of depot capabilities because the next set in the data was a dummy set with a negative value for depot 1, instructing the program to stop.

This last solution, which was the optimal flow for the constraints, uses a maximum of 34 trucks from the "unlimited" depot in one "day". This is indeed less than the capability it was given of 50. We may then recalculate the total fixed cost for this schedule as 31400, which is smaller than for the preceding case where two depots were used to their limit. The sum of this fixed cost plus the optimal cost of flow, 242000, however, is 273400 or slightly larger than the number, 267700, obtained in the preceding case. It appears, therefore, that it is not economical to eliminate the first depot.

The significance of this difference in cost is likely larger than at first apparent since the second depot probably cannot be as large as desired, and with two limited depots an even smaller cost may be obtainable by trying different limits. This is why the program contains the option of automatically generating all possible combinations of depot capabilities.

VIII.6 Program Listing

The source listing of SCHED1 follows. Note that, although the lines are numbered in increasing order, the numbers are not necessarily consecutive.

The listing contains some references to itself as "OPTFLO" as this was one of the names used for it during development.

```
C ************* PROGRAM OPTFLO **************
      COMMONR(100),LOC(101),C(2000),SN(2000),EN(2000),N,Z
      COMMON/NEGCYC/P(100),BP(100),ST(100),ET(100),PZ(100),MT,CYC,B
      COMMON/CORRCO/RC(2000),DAY(2000),DEP(2000),SRCS,SNKS,SNKDAS,MI,
     *RDP(50),RTL(100)
      COMMON/ROUTCO/FD(100),ID(100),V,INFEAS
      COMMON/DEPCOM/DL(05),DPCP(05),DN,NMAX,NTK,ALL,SUM(05),RL(05),DA
      COMMON/COMIRO/CP(2000),DEPS,RZ,CFIX
      COMMON/SCRICO/ IJ(5),FC(5),ICP(5),ICPR(5),FCR(5),IJR(5),COST,DAYS
      DIMENSION ISOL(5,5),CPM(5,5,5),SRCTL(5),SNKTL(5),         DATP(20),
     *          SNKP(5,5),SNKC(5,5),SNKCP(5,5),SRCP(5,5),SRCC(5,5),
     *          SRCCP(5,5),TC(5,5,25),CFIXA(5),CFIXB(5)
      INTEGER R,SN,EN,Z,ST,ET,PZ,B,RC,DAY,DEP,SRCS,SNKS,SNKDAS,FD,V,CP,
     *        DEPS,U,DAYS,SRCDAS,DPO,CPM,SRCTL,SNKTL,DPCP,DATP,U1,U2,V1,
     *        V2,SNKP,SRCP,DATYPS,SRCCP,SNKCP,SRCRDS,SRCARD,SNKRDS,
     *        SNKARD,RDP,RTL,DA,DN,DL,RL,SUM
      LOGICAL ISOL,INFEAS,P1,CYC,SCRIB(5),ENUM,ALL
      DATA IHENUM/4HENUM/
C I/O FOR DATA
      READ(5,900) SRCS,SNKS,DEPS,DAYS,DATYPS,Z,RZ,NH,SCRIB
      WRITE(6,901)SRCS,SNKS,DEPS,DAYS,DATYPS,Z,RZ,NH,SCRIB
      DO 0010 U=1,SRCS
      DO 0010 V=1,SNKS
 0010 ISOL(U,V)=.FALSE.
      DO 0030 I=1,DATYPS
      WRITE(6,902) I
      READ (5,903) (U,SRCP(U,I),J=1,SRCS)
      WRITE(6,904) (U,SRCP(U,I),U=1,SRCS)
      READ (5,905) (U,SRCC(U,I),J=1,SRCS)
      WRITE(6,906) (U,SRCC(U,I),U=1,SRCS)
      READ (5,903) (U,SRCCP(U,I),J=1,SRCS)
      WRITE(6,907) (U,SRCCP(U,I),U=1,SRCS)
      READ (5,903) (V,SNKP(V,I),J=1,SNKS)
      WRITE(6,908) (V,SNKP(V,I),V=1,SNKS)
      READ (5,905) (V,SNKC(V,I),J=1,SNKS)
      WRITE(6,909) (V,SNKC(V,I),V=1,SNKS)
      READ (5,903) (V,SNKCP(V,I),J=1,SNKS)
      WRITE(6,910) (V,SNKCP(V,I),V=1,SNKS)
      WRITE(6,911)
      DO 0030 U=1,SRCS
      K=(I-1)*DEPS
      DO 0030 DPO=1,DEPS
      K=K+1
      READ (5,912)(TC(U,V,K),V=1,SNKS)
      WRITE(6,913)U,DPO,(V,TC(U,V,K),V=1,SNKS)
      DO 0030 V=1,SNKS
      IF(TC(U,V,K).GE.RZ)ISOL(U,V)=.TRUE.
 0030 CONTINUE
      READ (5,924)(CFIXA(I),CFIXB(I),I=1,DEPS)
      WRITE(6,925)(I,CFIXA(I),CFIXB(I),I=1,DEPS)
      READ (5,903) (U,SRCTL(U),J=1,SRCS)
      WRITE(6,915) (U,SRCTL(U),U=1,SRCS)
      READ (5,903) (V,SNKTL(V),J=1,SNKS)
      WRITE(6,916) (V,SNKTL(V),V=1,SNKS)
      READ (5,918) (DATP(L),L=1,DAYS)
      WRITE(6,919) (DATP(L),L=1,DAYS)
      READ (5,920)J,NMAX
      WRITE(6,921)J,NMAX
      ENUM=J.EQ.IHENUM
      IF(.NOT.ENUM)GOTO2050
```

```
C INITIALIZE FOR DEPCAP                                                 OPF00543
      DN=DEPS                                                           OPF00545
      READ (5,903)(DPO,DL(DPO),I=1,DN)                                  OPF00550
      WRITE(6,922)(DPO,DL(DPO),DPO=1,DN)                                OPF00555
      J=0                                                               OPF00560
      DO 0035 I=1,DN                                                    OPF00565
 0035 J=J+DL(I)                                                         OPF00570
      IF(NMAX.GT.J.OR.NMAX.LE.0)NMAX=J                                  OPF00575
      DO 1000 I=1,DN                                                    OPF00580
      RL(I)=0                                                           OPF00583
 1000 SUM(I)=0                                                          OPF00585
      J=DN                                                              OPF00587
      L=0                                                               OPF00590
      DO 1010 I=1,DN                                                    OPF00593
      RL(J)=RL(J)+L                                                     OPF00595
      L=L+DL(J)                                                         OPF00597
 1010 J=J-1                                                             OPF00600
      N=0                                                               OPF00603
      DA=0                                                              OPF00605
      ALL=.FALSE.                                                       OPF00607
      GOTO2100                                                          OPF00610
C BEGINNING OF BIG LOOP ... GENERATE DEPOT CAPABILITIES                  OPF00613
 2000 IF(ENUM)GOTO2100                                                  OPF00615
 2050 READ (5,903)(DPO,DPCP(DPO),I=1,DEPS)                              OPF00620
      IF(DPCP(1).LT.0)STOP                                              OPF00625
      GOTO2200                                                          OPF00630
 2100 CALL DEPCAP                                                       OPF00635
      IF(ALL)STOP                                                       OPF00640
 2200 WRITE(6,917)(I,DPCP(I),I=1,DEPS)                                  OPF00645
      CFIX=0.0                                                          OPF00650
      DO 2300 I=1,DEPS                                                  OPF00655
 2300 CFIX=CFIX+CFIXA(I)+CFIXB(I)*FLOAT(DPCP(I))                        OPF00660
      WRITE(6,923)CFIX                                                  OPF00665
C BEGIN SETTING UP NETWORK                                              OPF00670
      SNKDAS=SNKS*DAYS                                                  OPF00680
      SRCDAS=SRCS*DAYS                                                  OPF00690
      N=SNKDAS+SRCDAS                                                   OPF00700
      DO 0040 U=1,SRCS                                                  OPF00710
      DO 0040 V=1,SNKS                                                  OPF00720
      IF(TSOL(U,V)) GO        TO 0040                                   OPF00730
      DO 0039 DPO=1,DEPS                                                OPF00740
 0039 CPP(U,V,DPO)=MIN0(SRCTL(U),SNKTL(V),DPCP(DPO))                    OPF00750
 0040 CONTINUE                                                          OPF00760
C FIRST DO ALL LINKS LEAVING SINKS                                      OPF00770
      V=0                                                               OPF00780
      J=0                                                               OPF00790
      K=SNKDAS                                                          OPF00800
      K1=0                                                              OPF00810
      LDJ=-DEPS                                                         OPF00820
      U2=SNKDAS-SRCS                                                    OPF00830
      DO 0100 L=1,DAYS                                                  OPF00840
      LDJ=LDJ+DEPS                                                      OPF00850
      I=DATP(L)                                                         OPF00860
      IF(L.EQ.DAYS) K1=SNKDAS                                           OPF00870
      U2=U2+SRCS                                                        OPF00880
      DO 0060 V1=1,SNKS                                                 OPF00890
      V=V+1                                                             OPF00900
      LOC(V)=J+1                                                        OPF00910
      FD(V)=-SNKP(V1,I)                                                 OPF00920
      RTL(V)=SNKTL(V1)                                                  OPF00930
      DO 0050 U1=1,SRCS
      IF(ISOL(U1,V1)) GO       TO 0050
      U=U1+U2
      IDJ=LDJ
      DO 0049 DPO=1,DEPS
      J=J+1
      SN(J)=V
      EN(J)=U
      C(J)=RZ
      CP(J)=0
      IDJ=IDJ+1
      DEP(J)=IDJ
      RDP(IDJ)=DPCP(DPO)
 0049 DAY(J)=L
 0050 CONTINUE
      J=J+1
      SN(J)=V
      EN(J)=V-SNKS+K
      C(J)=RZ
      CP(J)=0
      J=J+1
      SN(J)=V
      EN(J)=V+SNKS-K1
      C(J)=SNKC(V1,I)
 0060 CP(J)=SNKCP(V1,I)
 0100 K=0
      SNKRDS=J
      SNKARD=SNKRDS/DAYS
C SECOND DO ALL LINKS LEAVING SOURCES
      K=SRCDAS
      K1=0
      U=V
      LDJ=-DEPS
      V2=-SNKS
      DO 0200 L=1,DAYS
      LDJ=LDJ+DEPS
      I=DATP(L)
      V2=V2+SNKS
      IF(L.EQ.DAYS) K1=SRCDAS
      DO 0160 U1=1,SRCS
      U=U+1
      J=J+1
      FD(U)=SRCP(U1,I)
      RTL(U)=SRCTL(U1)
      LOC(U)=J
      SN(J)=U
      EN(J)=U-SRCS+K
      C(J)=RZ
      CP(J)=0
      DO 0150 V1=1,SNKS
      IF(ISOL(U1,V1))          GO TO 0150
      V=V1+V2
      IDJ=LDJ
      M=DEPS*(I-1)
      DO 0149 DPO=1,DEPS
      M=M+1
      J=J+1
      SN(J)=U
      EN(J)=V
      CP(J)=CPM(U1,V1,DPO)
      C(J)=TC(U1,V1,M)                                                  OPF01530
      IDJ=IDJ+1                                                         OPF01560
      DEP(J)=IDJ                                                        OPF01570
      RDP(IDJ)=DPCP(DPO)                                                OPF01580
 0149 DAY(J)=L                                                          OPF01590
 0150 CONTINUE                                                          OPF01600
      J=J+1                                                             OPF01610
      SN(J)=U                                                           OPF01620
      EN(J)=U+SRCS-K1                                                   OPF01630
      C(J)=SRCC(U1,I)                                                   OPF01640
 0160 CP(J)=SRCCP(U1,I)                                                 OPF01650
 0200 K=0                                                               OPF01660
      M=J                                                               OPF01670
      LOC(N+1)=M+1                                                      OPF01680
      SRCRDS=M-SNKRDS                                                   OPF01690
      SRCARD=SRCRDS/DAYS                                                OPF01700
C DETERMINATION OF RECIPROCAL ARCS                                      OPF01710
C FIRST DO FIRST DAY TRANSPORT ARCS AND SINK HOLDOVER ARCS              OPF01720
      J=1                                                               OPF01730
      DO 250 V=1,SNKS                                                   OPF01740
      J1=LOC(V+1)-3                                                     OPF01750
 0238 U=EN(J)                                                           OPF01760
      IARC=LOC(U)+1                                                     OPF01770
      IARC1=LOC(U+1)-2                                                  OPF01780
      DO 0240 I=IARC,IARC1                                              OPF01790
      IF(EN(I).EQ.V) GO        TO 0241                                  OPF01800
 0240 CONTINUE                                                          OPF01810
 0241 DO 0242 DPO=1,DEPS                                                OPF01820
      RC(I)=J                                                           OPF01830
      RC(J)=I                                                           OPF01840
      I=I+1                                                             OPF01850
 0242 J=J+1                                                             OPF01860
      IF(J.LE.J1) GO           TO 0238                                  OPF01870
      I=J+SNKRDS-SNKARD+1                                               OPF01880
      RC(J)=I                                                           OPF01890
      RC(I)=J                                                           OPF01900
      J=J+2                                                             OPF01910
 0250 CONTINUE                                                          OPF01920
C THEN DUPLICATE ON OTHER DAYS                                          OPF01930
      V=SNKS+1                                                          OPF01940
 0260 J1=LOC(V+1)-3                                                     OPF01950
 0270 I=RC(J-SNKARD)+SRCARD                                             OPF01960
      DO 0275 DPO=1,DEPS                                                OPF01970
      RC(J)=I                                                           OPF01980
      RC(I)=J                                                           OPF01990
      I=I+1                                                             OPF02000
 0275 J=J+1                                                             OPF02010
      IF(J.LE.J1) GO           TO 0270                                  OPF02020
      I=J-SNKARD +1                                                     OPF02030
      RC(I)=J                                                           OPF02040
      RC(J)=I                                                           OPF02050
      IF(V.EQ.SNKDAS) GO       TO 0290                                  OPF02060
      V=V+1                                                             OPF02070
      J=J+2                                                             OPF02080
      GO                       TO 0260                                  OPF02090
C FINALLY DO SOURCE HOLDOVER ARCS                                       OPF02100
 0290 U1=N-SRCS+1                                                       OPF02110
      I1=SNKDAS+1                                                       OPF02120
      I2=SNKDAS+SRCS                                                    OPF02130
      DO 0295 U2=I1,I2                                                  OPF02140
      U1=U1+1
      J=LOC(U2)
      I=LOC(U1)-1
      RC(J)=I
 0295 RC(I)=J
      U1=I1
      I1=I2+1
      DO 0300 U2=I1,N
      U1=U1+1
      J=LOC(U2)
      I=LOC(U1)-1
      RC(J)=I
 0300 RC(I)=J
      IF(SCRIB(1))CALLSCRIBE(1)
C
C STEP 1 OF PART A HAS BEEN COMPLETED CONCURRENTLY WITH NETWORK
C SETUP.. NOW IN STEP 2 OF PART A THE FLOWS IN AND OUT OF EACH
C NODE WILL BE BALANCED
      I1=SNKDAS+1
      DO 0350 U=I1,N
      IF(FD(U).LE.0) GO       TO 0350
 0335 CALL ROUTE(U)
      IF(INFEAS) GO           TO 9999
      MI=MINFLO(U,V)
      IF(FD(U).LT.MI) MI=FD(U)
      IF(-FD(V).LT.MI) MI=-FD(V)
      CALL CORR(U,V)
      FD(V)=FD(V)+MI
      FD(U)=FD(U)-MI
      IF(FD(U).GT.0) GO       TO 0335
 0350 CONTINUE
      IF(SCRIB(2))CALLSCRIBE(2)
C NOW COMES PART B.. FOLLOWING DOMSCHKE, WE BEGIN WITH A SHOTGUN
C APPROACH, LOOKING FOR A NEG CYCLE STARTING FROM ARBITRARY NODES
C U, GOING ON TO U+1 WHETHER OR NOT A NEG CYCLE IS FOUND.    AS
C SOON AS NH CONSECUTIVE NODES U HAVE NOT YIELDED ANY NEG CYCLE,
C WE LEAVE THIS ROUTINE AND GO ON TO A MORE METHODICAL SEARCH
C STARTING FROM NODES NOT YET REACHED.
      P1=.TRUE.
C WHEN P1 BECOMES FALSE, THE SET FD INDICATING REACHED NODES HAS
C BEEN DEFINED ONCE AND ONLY THE CHANGES THEN NEED BE RECORDED.
      NOCYC=0
C WHEN NOCYC GROWS TO NH, THE SHOTGUN APPROACH IS ABANDONED.
 0400 DO 0450 U=1,N
      CALL CYCLE(U)
      IF(.NOT.CYC) GO         TO 0410
      NOCYC=0
      MI=MINFLO(B,B)
      CALL CORR(B,B)
      IF(SCRIB(3))CALLSCRIBE(3)
      GO                      TO 0450
 0410 IF(P1) GO               TO 0420
      DO 0415 V=1,N
      IF(D(V).LT.RZ) FD(V)=0
 0415 CONTINUE
      GO                      TO 0430
 0420 DO 425 V=1,N
      FD(V)=Z
      IF(D(V).LT.RZ) FD(V)=0
 0425 CONTINUE
```

```
      P1=.FALSE.                                                        OPF02730
 0430 NOCYC=NOCYC+1                                                     OPF02740
      IF(NOCYC.GE.NH) GO        TO 0500                                 OPF02750
 0450 CONTINUE                                                          OPF02760
      GO                        TO 0400                                 OPF02770
C HERE BEGINS THE SEARCH USING UNREACHED NODES AS STARTING POINTS       OPF02780
 0500 DO 0550 U=1,N                                                     OPF02790
      IF(FD(U).LE.0) GO         TO 0550                                 OPF02800
 0535 CALL CYCLE(U)                                                     OPF02810
      IF(.NOT.CYC) GO           TO 0540                                 OPF02820
      MI=MINFLO(B,B)                                                    OPF02830
      CALL CORR(B,B)                                                    OPF02840
      IF(SCRIB(4))CALLSCRIBE(4)                                         OPF02845
      GO                        TO 0535                                 OPF02850
 0540 I=U+1                                                             OPF02860
      DO 0549 V=1,N                                                     OPF02870
      IF(D(V).LT.RZ) FD(V)=0                                            OPF02880
 0549 CONTINUE                                                          OPF02890
 0550 CONTINUE                                                          OPF02920
C FLOW IS NOW OPTIMAL                                                   OPF02930
      IF(SCRIB(5))CALLSCRIBE(5)                                         OPF02940
      GOTO2000                                                          OPF02950
 9999 WRITE(6,9000)                                                     OPF02960
      GOTO2000                                                          OPF02970
C****************** FORMATS ******************                          OPF03370
 0900 FORMAT(5I5,I20,E5.0,I10,5X,5L1)                                   OPF03380
 0901 FORMAT(5H1SRCS,I5,5X,4HSNKS,I5,5X,4HDEPS,I5,5X,4HDAYS,I5,5X,6HDAYTYOPF03390
     *PS,I5/3H0Z=,I20,10X,3HRZ=,1PE8.1,10X,3HNH=,I5,10X,6HSCRIB=,5L2)   OPF03400
 0902 FORMAT(1H0/16H0DATA FOR DAY TYPE,I5,3H.../)                       OPF03410
 0903 FORMAT(5(I5,I10))                                                 OPF03420
 0904 FORMAT(26H SOURCE PRODUCTION, SRCP()/(1H ,5(I5,I10)))             OPF03430
 0905 FORMAT(5(I5,E10.0))                                               OPF03440
 0906 FORMAT(34H SOURCE HOLDOVER UNIT COST, SRCC()/(1H ,5(I5,1PE10.3))) OPF03450
 0907 FORMAT(30H SOURCE HOLDOVER LIMIT,SRCCP()/(1H ,5(I5,I10)))         OPF03460
 0908 FORMAT(24H SINK PRODUCTION, SNKP()/(1H ,5(I5,I10)))               OPF03470
 0909 FORMAT(27H SINK HOLDOVER COST, SNKC()/(1H ,5(I5,1PE10.3)))        OPF03480
 0910 FORMAT(29H SINK HOLDOVER LIMIT, SNKCP()/(1H ,5(I5,I10)))          OPF03490
 0911 FORMAT(62H0COST PER TRUCK-DAY, LISTING SOURCE, DEPOT, THEN VARIOUSOPF03500
     * SINKS)                                                           OPF03510
 0912 FORMAT(5X,5(5X,E10.0)/(5X,5(5X,E10.0)))                           OPF03520
 0913 FORMAT(1H ,I2,I3,5(I5,1PE10.3)/(1H ,5X,5(I5,1PE10.3)))            OPF03530
 0915 FORMAT(26H0DATA SAME FOR ALL DAYS.../34H0SOURCE DAILY TRUCK LIMIT,OPF03540
     * SRCTL()/(1H ,5(2I5,5X)))                                         OPF03550
 0916 FORMAT(32H SINK DAILY TRUCK LIMIT, SNKTL()/(1H ,5(2I5,5X)))       OPF03560
 0917 FORMAT(32H DEPOT DAILY TRUCK LIMIT, DPCP()/(1H ,5(2I5,5X)))       OPF03570
 0918 FORMAT(80I1)                                                      OPF03580
 0919 FORMAT(26H0DAY TYPE SEQUENCE, DATP()/(1H ,80I1))                  OPF03590
 0920 FORMAT(A4,I6)                                                     OPF03600
 0921 FORMAT(37H0DEPOT CAPABILITY GENERATING MODE IS ,A4,11H WITH NMAX=,OPF03605
     *I5)                                                               OPF03606
 0922 FORMAT(38H0MAXIMUM DEPOT DAILY TRUCK LIMIT, DL()/(1H ,5(2I5,5X))) OPF03610
 0923 FORMAT(33H TOTAL FIXED CHARGE FOR DEPOTS IS,E15.7)                OPF03620
 0924 FORMAT(4E20.0)                                                    OPF03630
 0925 FORMAT(33H0FIXED CHARGES WILL BE CALCULATED/(12H ..FOR DEPOT,I4,  OPF03640
     *3H AS,E15.6,5H PLUS,E15.6,28H TIMES ITS DAILY TRUCK LIMIT))       OPF03645
 9000 FORMAT(20H0SOLUTION INFEASIBLE)                                   OPF03670
      END                                                               OPF03690
      SUBROUTINE ROUTE(U)                                               OPF03700
C ROUTE(U) FINDS A PATH FROM U, WHICH HAS +VE FD, TO SOME NODE V        OPF03710
C WHICH HAS -VE FD, AS REQUIRED IN STEP 2 OF PART A..  THIS IS DONE     OPF03720
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C BY CONSTRUCTING A TREE ROOTED AT U.                                   OPF03730
C WHERE PARALLEL ARCS ARE ENCOUNTERED BETWEEN A PAIR OF NODES, THE      OPF03740
C FIRST ONE WITH RESIDUAL CAPACITY IS CHOSEN.                           OPF03750
C FIRST ALL SUCCESSORS OF U ARE LABELLED WITH ID=1, AND ALL OTHER NODES OPF03760
C ARE LABELLED ID=Z.  ID IS LEVEL OF TREE ON WHICH NODE HAS BEENCONNECTDOPF03770
      COMMCNR(100),LOC(101),C(2000),SN(2000),EN(2000),N,Z               OPF03780
      COMMON/ROUTCO/FD(100),ID(100),V,INFEAS                            OPF03790
      COMMON/COM1RU/CP(2000),DEPS,RZ,CFIX                               OPF03800
      INTEGER R,SN,EN,Z,FD,CP,DEPS,U,V                                  OPF03810
      LOGICAL INFEAS,NOEXT                                              OPF03820
      INFEAS=.TRUE.                                                     OPF03830
C WHEN INFEAS BECOMES FALSE, A PATH HAS BEEN COMPLETED.                 OPF03840
      DO 0005 I=1,N                                                     OPF03850
 0005 ID(I)=Z                                                           OPF03860
      ID(U)=0                                                           OPF03870
      IARC1=LOC(U+1)-2                                                  OPF03880
      I1=LOC(U)+1                                                       OPF03890
      I2=I1-1+DEPS                                                      OPF03900
 0008 I=EN(I1)                                                          OPF03910
      DO 0010 J=I1,I2                                                   OPF03920
      IF(C(J).EQ.RZ) GO       TO 0010                                   OPF03930
      ID(I)=1                                                           OPF03940
      R(I)=J                                                            OPF03950
      IF(FD(I).GE.0) GO       TO 0020                                   OPF03960
      V=I                                                               OPF03970
      INFEAS=.FALSE.                                                    OPF03980
      RETURN                                                            OPF03990
 0010 CONTINUE                                                          OPF04000
 0020 IF(I2.EQ.IARC1) GO       TO 0025                                  OPF04010
      I1=I2+1                                                           OPF04020
      I2=I2+DEPS                                                        OPF04030
      GO TO           0008                                              OPF04040
 0025 J=I2+1                                                            OPF04050
      IF(C(J).EQ.RZ) GO       TO 0030                                   OPF04060
      I=EN(J)                                                           OPF04070
      ID(I)=1                                                           OPF04080
      R(I)=J                                                            OPF04090
C THE TREE MAY HAVE UP TO N-1 LEVELS                                    OPF04100
 0030 N1=N-1                                                            OPF04110
      DO 0100 K=2,N1                                                    OPF04120
      NOEXT=.TRUE.                                                      OPF04130
C IF NOEXT REMAINS TRUE THIS MEANS NO PATH EXTENDS TO LEVEL K           OPF04140
      K1=K-1                                                            OPF04150
      DO 0080 I=1,N                                                     OPF04160
      IF(ID(I).NE.K1) GO       TO 0080                                  OPF04170
C NOW A NODE HAS BEEN FOUND CONNECTED ON LEVEL K-1.. LOOK FOR A         OPF04180
C SUCCESSOR NOT YET CONNECTED                                           OPF04190
      I1=LOC(I)                                                         OPF04200
      IARC1=LOC(I+1)-1                                                  OPF04210
      DO 0079 J=I1,IARC1                                                OPF04220
      IF(C(J).GE.RZ) GO       TO 0079                                   OPF04230
      I2=EN(J)                                                          OPF04240
      IF(ID(I2).LT.Z) GO       TO 0079                                  OPF04250
      ID(I2)=K                                                          OPF04260
      R(I2)=J                                                           OPF04270
      NOEXT=.FALSE.                                                     OPF04280
      IF(FD(I2).GE.0) GO       TO 0079                                  OPF04290
      V=I2                                                              OPF04300
      INFEAS=.FALSE.                                                    OPF04310
      RETURN                                                            OPF04320
 0079 CONTINUE
 0080 CONTINUE
      IF(NOEXT)       RETURN
 0100 CONTINUE
      RETURN
      END
      FUNCTION MINFLO(U,V)
C FINDS MINIMUM RESIDUAL CAPACITY OF BRANCHES IN ROUTE R FROM U TO V
      COMMONR(100),LOC(101),C(2000),SN(2000),EN(2000),N,Z
      COMMON/COMIRU/CP(2000),DEPS,RZ,CFIX
      INTEGER R,SN,EN,Z,CP,DEPS,U,V
      K=Z
      I=V
 0010 J=R(I)
      IF(CP(J).LT.K) K=CP(J)
      I=SN(J)
      IF(I.NE.U) GO       TO 0010
      MINFLO=K
      RETURN
      END
      SUBROUTINE CORR(U,V)
C CORRECTS FLOW ON PATH FROM U TO V.. FLOW IS IMPLICIT IN CP
      COMMONR(100),LOC(101),C(2000),SN(2000),EN(2000),N,Z
      COMMON/CORRCO/RC(2000),DAY(2000),DEP(2000),SRCS,SNKS,SNKDAS,MI,
     *RDP(50),RTL(100)
      COMMON/COMIRU/CP(2000),DEPS,RZ,CFIX
      INTEGER R,SN,EN,Z,RC,DAY,DEP,SRCS,SNKS,SNKDAS,CP,DEPS,U,V,DJ,VJ,
     *          RDP,RTL
      LOGICAL P1,P2
      I2=V
 0010 J=R(I2)
      I=RC(J)
      I1=SN(J)
      IF(CP(I).LE.0) C(I)=-C(J)
      P1= I1.LE.SNKDAS
      P2= I2.GT.SNKDAS
      IF(P1.AND.P2) GO  TO 0055
      IF(P1.OR.P2) GO          TO 0085
C J IS A TRANSPORT ARC FROM SOURCE TO SINK
      DJ=DEP(J)
      RDP(DJ)=RDP(DJ)-MI
      RTL(I1)=RTL(I1)-MI
      RTL(I2)=RTL(I2)-MI
      I=RC(J)
      CP(I)=CP(I)+MI
      GO                 TO 0065
C J IS THE RECIPROCAL OF A TRANSPORT ARC FROM SOURCE TO SINK
 0055 DJ=DEP(J)
      RDP(DJ)=RDP(DJ)+MI
      RTL(I1)=RTL(I1)+MI
      RTL(I2)=RTL(I2)+MI
      CP(J)=CP(J)-MI
      IF(CP(J).LE.0) C(J)=RZ
C REVISE CP FOR ALL TRANSPORT ARCS OF DAY
 0065 L=SNKDAS+SRCS*DAY(J)
      K=L-SRCS+1
      DO 0076 VJ=K,L
      IARC=LOC(VJ)+1
      IARC1=LOC(VJ+1)-2
      DO 0076 JD=IARC,IARC1
      IRJ=RTL(VJ)                                                       OPF04930
      IF(IRJ.LE.0) GO   TO 0075                                         OPF04940
      IR=ROP(DEP(JD))                                                   OPF04950
      IF(IRJ.LE.IR) GO  TO 0074                                         OPF04960
      IRJ=IR                                                            OPF04970
      IF(IRJ.LE.0) GO   TO 0075                                         OPF04980
 0074 IR=RTL(EN(JD))                                                    OPF04990
      IF(IRJ.GT.IR) IRJ=IR                                              OPF05000
      IF(IRJ.GE.1) GO   TO 0076                                         OPF05010
 0075 C(JD)=RZ                                                          OPF05020
 0076 CP(JD)=IRJ                                                        OPF05030
      GO                TO 0100                                         OPF05040
C J IS A HOLDOVER ARC FOR A SOURCE OR A SINK                            OPF05050
 0085 CP(J)=CP(J)-MI                                                    OPF05060
      CP(I)=CP(I)+MI                                                    OPF05070
      IF(CP(J).LE.0) C(J)=RZ                                            OPF05080
 0100 IF(I1.EQ.0) RETURN                                                OPF05090
      I2=I1                                                             OPF05100
      GO TO        0010                                                 OPF05110
      END                                                               OPF05120
      SUBROUTINE CYCLE(Q)                                               OPF05130
C A PROCEDURE FOR FINDING  A NEGATIVE CYCLE IN A VALUED DIRECTED MULTI- OPF05140
C GRAPH... ADAPTED FROM DOMSCHKE'S ALGOL PROCEDURE  *ZYKL FORD* ...     OPF05150
C SOME MODIFICATIONS HAVE BEEN MADE TO ACCOUNT FOR MULTIPLE ARCS BETWEENOPF05160
C EACH PAIR OF NODES... THE PROCEDURE USES THE APPROACH OF FORD'S       OPF05170
C SHORTEST CHAIN ALGORITHM                                              OPF05180
C THIS SUBROUTINE IS BASED ON DOMSCHKE'S *GRUNDPROZESS* (MAIN PROCESS). OPF05190
C IT CALLS SUBROUTINE NEGARC WHICH IS BASED ON DOMSCHKE'S *PROZEDUR*.   OPF05200
      COMMONR(100),LOC(101),C(2000),SN(2000),EN(2000),N,Z               OPF05210
      COMMON/NEGCYC/D(100),DP(100),ST(100),ET(100),PZ(100),MT,CYC,B     OPF05220
      INTEGER R,SN,EN,Z,ST,ET,PZ,B,Q,H                                  OPF05230
      LOGICAL CYC,P                                                     OPF05240
      MT=0                                                              OPF05250
      CYC=.FALSE.                                                       OPF05260
      DO 0010 I=1,N                                                     OPF05270
      D(I)=Z                                                            OPF05280
      ST(I)=0                                                           OPF05290
 0010 R(I)=0                                                            OPF05300
      D(Q)=0.0                                                          OPF05310
      R(Q)=Q                                                            OPF05320
      IARC=LOC(Q)                                                       OPF05330
      IARC1=LOC(Q+1)-1                                                  OPF05340
C FIRST FIND SHORTEST PATHS TO Q*S SUCCESSORS                           OPF05350
      DO 0020 J=IARC,IARC1                                              OPF05360
      H=EN(J)                                                           OPF05370
      SU=C(J)                                                           OPF05380
      IF(SU.GE.D(H)) GO       TO 0020                                   OPF05390
      R(H)=-J                                                           OPF05400
C NEGATIVE R(H) IMPLIES H IS IN SET A                                   OPF05410
      D(H)=SU                                                           OPF05420
C TEST FOR NEGATIVE ARC                                                 OPF05430
      IF(SU.GE.0.0) GO        TO 0020                                   OPF05440
C ADD NODE H TO SET T UNLESS IT IS ALREADY THERE                        OPF05450
      IF(ST(H).NE.0) GO       TO 0020                                   OPF05460
      PZ(H)=1                                                           OPF05470
      MT=MT+1                                                           OPF05480
      ST(H)=MT                                                          OPF05490
      ET(MT)=H                                                          OPF05500
 0020 CONTINUE                                                          OPF05510
      IF(MT.LE.0) GO          TO 0030                                   OPF05520
      CALL NEGARC(Q)                                                    OPF05530
      IF(CYC)           RETURN                                          OPF05540
 0030 P=.FALSE.                                                         OPF05550
C TEST EACH NODE I AS PART OF AN IMPROVED PATH TO ITS SUCCESSORS FROM Q OPF05560
      DO 0060 I=1,N                                                     OPF05570
C IF NODE I IS NOT IN SET A GO ON TO I+1                                OPF05580
      IF(R(I).GE.0) GO       TO 0060                                    OPF05590
C REMOVE I FROM SET A                                                   OPF05600
      R(I)=-R(I)                                                        OPF05610
      IARC=LOC(I)                                                       OPF05620
      IARC1=LOC(1+I)-1                                                  OPF05630
      DO 0050 J=IARC,IARC1                                              OPF05640
      H=EN(J)                                                           OPF05650
      SU=D(I)+C(J)                                                      OPF05660
      IF(SU.GE.D(H)) GO       TO 0050                                   OPF05670
      D(H)=SU                                                           OPF05680
      R(H)=-J                                                           OPF05690
C NEGATIVE R(H) IMPLIES H IS IN SET A                                   OPF05700
C P TELLS WHETHER ANY PATHS HAVE BEEN SHORTENED IN MAIN PROCESS         OPF05710
      P=.TRUE.                                                          OPF05720
C TEST FOR NEGATIVE ARC                                                 OPF05730
      IF(C(J).GE.0.0) GO       TO 0050                                  OPF05740
C ADD H TO SET T UNLESS IT IS ALREADY THERE                             OPF05750
      IF(ST(H).NE.0) GO       TO 0050                                   OPF05760
      MT=MT+1                                                           OPF05770
      ST(H)=MT                                                          OPF05780
      ET(MT)=H                                                          OPF05790
      PZ(H)=1                                                           OPF05800
 0050 CONTINUE                                                          OPF05810
      IF(MT.LE.0) GO       TO 0060                                      OPF05820
      K=I                                                               OPF05830
      CALL NEGARC(K)                                                    OPF05840
      IF(CYC)           RETURN                                          OPF05850
 0060 CONTINUE                                                          OPF05860
      IF(P) GO       TO 0030                                            OPF05870
      RETURN                                                            OPF05880
      END                                                               OPF05890
      SUBROUTINE NEGARC(P)                                              OPF05900
      COMMONR(100),LOC(101),C(2000),SN(2000),EN(2000),N,Z               OPF05910
      COMMON/NEGCYC/D(100),DP(100),ST(100),ET(100),PZ(100),MT,CYC,B     OPF05920
      INTEGER R,SN,EN,Z,ST,ET,PZ,B,P,H                                  OPF05930
      LOGICAL CYC                                                       OPF05940
      DO 0005 I=1,N                                                     OPF05950
      DP(I)=0.0                                                         OPF05960
      IF(ST(I).NE.0) DP(I)=C(-R(I))                                     OPF05970
 0005 CONTINUE                                                          OPF05980
C TRY EACH NODE IN T AS PART OF AN IMPROVD PATH TO ITS SUCCESSORS FROM QOPF05990
 0010 I=ET(MT)                                                          OPF06000
      ST(I)=0                                                           OPF06010
      MT=MT-1                                                           OPF06020
      R(I)=-R(I)                                                        OPF06030
C NODE I HAS NOW BEEN REMOVED FROM SETS A AND T                         OPF06040
      IARC=LOC(I)                                                       OPF06050
      IARC1=LOC(I+1)-1                                                  OPF06060
      DO 0090 J=IARC,IARC1                                              OPF06070
      H=EN(J)                                                           OPF06080
      SU=D(I)+C(J)                                                      OPF06090
      IF(SU.GE.D(H)) GO       TO 0090                                   OPF06100
      D(H)=SU                                                           OPF06110
C PATH FROM Q TO H HAS BEEN SHORTENED... TEST FOR COMPLETION OF NEG CYCLOPF06120
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      SU=DP(I)+C(J)                                                     OPF06130
      IF(SU.GE.0.0) GO       TO 0080                                    OPF06140
      IF(H.NE.P) GO       TO 0020                                       OPF06150
C CASE 1 ENCOUNTERED                                                    OPF06160
      R(H)=J                                                            OPF06170
      B=H                                                               OPF06180
      CYC=.TRUE.                                                        OPF06190
      RETURN                                                            OPF06200
 0020 IF(DP(H).GE.0.0.OR.DP(H).LE.SU) GO       TO 0050                  OPF06210
      IF(PZ(H).GE.PZ(I)) GO       TO 0050                               OPF06220
      B=I                                                               OPF06230
      K1=PZ(I)-PZ(H)                                                    OPF06240
      DO 0030 K=1,K1                                                    OPF06250
 0030 B=SN(R(B))                                                        OPF06260
      IF(B.NE.H) GO       TO 0050                                       OPF06270
C CASE 2A ENCOUNTERED                                                   OPF06280
      R(H)=J                                                            OPF06290
      CYC=.TRUE.                                                        OPF06300
      RETURN                                                            OPF06310
C OTHERWISE CASE 2B AS FOLLOWS                                          OPF06320
C IF H NOT IN T THEN ADD IT IN... ELSE MOVE IT TO END POSITION.         OPF06330
 0050 K1=ST(H)                                                          OPF06340
      IF(K1.EQ.0) GO       TO 0070                                      OPF06350
      IF(K1.EQ.MT) GO       TO 0075                                     OPF06360
      K2=MT-1                                                           OPF06370
      DO 0060 K=K1,K2                                                   OPF06380
      B=ET(K+1)                                                         OPF06390
      ET(K)=B                                                           OPF06400
 0060 ST(B)=ST(B)-1                                                     OPF06410
 0070 MT=MT+1                                                           OPF06420
      ET(MT)=H                                                          OPF06430
      ST(H)=MT                                                          OPF06440
 0075 DP(H)=SU                                                          OPF06450
      PZ(H)=PZ(I)+1                                                     OPF06460
C ADD H TO A                                                            OPF06470
 0080 R(H)=-J                                                           OPF06480
 0090 CONTINUE                                                          OPF06490
      IF(MT.GT.0) GO       TO 0010                                      OPF06500
      RETURN                                                            OPF06510
      END                                                               OPF06520
      SUBROUTINE SCRIBF(NG)                                             OPF06530
      COMMONR(100),LOC(101),C(2000),SN(2000),EN(2000),N,Z               OPF06534
      COMMON/CORRCO/RC(2000),DAY(2000),DEP(2000),SRCS,SNKS,SNKDAS,MT,   OPF06535
     *RDP(50),RTL(100)                                                  OPF06536
      COMMON/COMIRU/CP(2000),DEPS,RZ,CFIX                               OPF06537
      COMMON/SCRICO/ IJ(5),FC(5),ICP(5),ICPR(5),FCR(5),IJR(5),COST,DAYS OPF06540
      INTEGER R,SN,EN,Z,RC,DAY,DEP,SRCS,SNKS,SNKDAS,RDP,RTL,CP,DEPS,DPO,OPF06545
     *                                                        DAYS,U1,V1OPF06546
      WRITE(6,5) NG                                                     OPF06550
      MDAY=-SNKS                                                        OPF06560
      I=SNKDAS                                                          OPF06570
      MARKU=1+SNKDAS                                                    OPF06580
      J1=SNKS                                                           OPF06590
      MARKV=1                                                           OPF06600
      COST=0.0                                                          OPF06610
      DO 0700 L=1,DAYS                                                  OPF06620
      WRITE(6,10) L                                                     OPF06630
      MDAY=MDAY+SNKS                                                    OPF06640
C SOURCE SINK ARCS AND THEIR RECIPROCALS                                OPF06650
      DO 0650 U1=1,SRCS                                                 OPF06660
      I=I+1                                                             OPF06670
      J=LOC(I)+1                                                        OPF06680
      IARC=LOC(I+1)-2                                                   OPF06690
 0630 DO 0640 DPO=1,DEPS                                                OPF06700
      JR=RC(J)                                                          OPF06710
      V1=FN(J)-MDAY                                                     OPF06720
      IF(CP(JR).LE.0) GO            TO 0635                             OPF06730
      COST=COST-C(JR)*FLOAT(CP(JR))                                     OPF06740
 0635 WRITE(6,20) U1,I,J,C(J),CP(J),DEP(J),DPO,DEP(JR),CP(JR),C(JR),JR, OPF06750
     ,                                                          FN(J),V1OPF06760
 0640 J=J+1                                                             OPF06770
      IF(J.LE.IARC) GO              TO 0630                             OPF06780
 0650 CONTINUE                                                          OPF06790
C SOURCE HOLDOVER ARCS AND THEIR RECIPROCALS                            OPF06800
      I1=MARKU                                                          OPF06810
      DO 0660 U1=1,SRCS                                                 OPF06820
      I1=I1+1                                                           OPF06830
      J=LOC(I1)-1                                                       OPF06840
      JR=RC(J)                                                          OPF06850
      IF(CP(JR).LE.0) GO            TO 0655                             OPF06860
      COST=COST-C(JR)*FLOAT(CP(JR))                                     OPF06870
 0655 IJ(U1)=J                                                          OPF06880
      FC(U1)=C(J)                                                       OPF06890
      ICP(U1)=CP(J)                                                     OPF06900
      ICPR(U1)=CP(JR)                                                   OPF06910
      FCR(U1)=C(JR)                                                     OPF06920
 0660 IJR(U1)=JR                                                        OPF06930
      WRITE(6,30)  (U1,U1=1,SRCS)                                       OPF06940
      WRITE(6,40)  (I1,I1=MARKU,I)                                      OPF06950
      WRITE(6,50)  (IJ(U1),U1=1,SRCS)                                   OPF06970
      WRITE(6,60)  (FC(U1),U1=1,SRCS)                                   OPF06980
      WRITE(6,70)  (ICP(U1),U1=1,SRCS)                                  OPF06990
      WRITE(6,80)  (ICPR(U1),U1=1,SRCS)                                 OPF07000
      WRITE(6,90)  (FCR(U1),U1=1,SRCS)                                  OPF07010
      WRITE(6,100) (IJR(U1),U1=1,SRCS)                                  OPF07020
      MARKU=I+1                                                         OPF07030
      U1=I+SRCS                                                         OPF07040
      WRITE(6,40)  (I1,I1=MARKU,U1)                                     OPF07050
      WRITE(6,35)  (U1,U1=1,SRCS)                                       OPF07060
C SINK HOLDOVER ARCS AND THEIR RECIPROCALS                              OPF07080
      I1=MARKV                                                          OPF07090
      DO 0670 V1=1,SNKS                                                 OPF07100
      I1=I1+1                                                           OPF07110
      J=LOC(I1)-1                                                       OPF07120
      JR=RC(J)                                                          OPF07130
      IF(CP(JR).LE.0) GO            TO 0665                             OPF07140
      COST=COST-C(JR)*FLOAT(CP(JR))                                     OPF07150
 0665 IJ(V1)=J                                                          OPF07160
      FC(V1)=C(J)                                                       OPF07170
      ICP(V1)=CP(J)                                                     OPF07180
      ICPR(V1)=CP(JR)                                                   OPF07190
      FCR(V1)=C(JR)                                                     OPF07200
 0670 IJR(V1)=JR                                                        OPF07210
      WRITE(6,110) (V1,V1=1,SNKS)                                       OPF07220
      WRITE(6,120) (I1,I1=MARKV,J1)                                     OPF07230
      WRITE(6,130) (IJ(V1),V1=1,SNKS)                                   OPF07240
      WRITE(6,140) (FC(V1),V1=1,SNKS)                                   OPF07250
      WRITE(6,150) (ICP(V1),V1=1,SNKS)                                  OPF07260
      WRITE(6,160) (ICPR(V1),V1=1,SNKS)                                 OPF07270
      WRITE(6,170) (FCR(V1),V1=1,SNKS)                                  OPF07280
      WRITE(6,180) (IJR(V1),V1=1,SNKS)                                  OPF07290
      MARKV=J1+1                                                        OPF07300
      J1=J1+SNKS                                                        OPF07310
      WRITE(6,120) (I1,I1=MARKV,J1)                                     OPF07320
 0700 WRITE(6,115) (V1,V1=1,SNKS)                                       OPF07340
      WRITE(6,200) COST                                                 OPF07350
      COST=COST+CFIX                                                    OPF07354
      WRITE(6,201)COST                                                  OPF07355
C********************* FORMATS *********************                    OPF07360
 0005 FORMAT(25H1SCRIBE CALLED FROM POINT,I2/)                          OPF07370
 0010 FORMAT(4H0DAY,I3,10X,86H SRC NOD ARC,J      C(J)      CP(J)  DEP(J) OPF07380
     -DPO DEP(JR) CP(JR)     C(JR)  RARC,JR NOD SNK)                    OPF07390
 0020 FORMAT(1H ,16X,3I4,2PE14.2,I6, I8,2I4,I10,1PE10.2,4X,3I4)         OPF07400
 0030 FORMAT(9H0      SRC,10I10)                                        OPF07410
 0035 FORMAT(9H       SRC,10I10)                                        OPF07415
 0040 FORMAT(9H       NOD,10I10)                                        OPF07420
 0050 FORMAT(9H       ARC,10I10)                                        OPF07430
 0060 FORMAT(9H    C(ARC),10(1PE10.2))                                  OPF07440
 0070 FORMAT(9H   CP(ARC),10I10)                                        OPF07450
 0080 FORMAT(9H CP(RARC),10I10)                                         OPF07460
 0090 FORMAT(9H   C(RARC),10(1PE10.2))                                  OPF07470
 0100 FORMAT(9H      RARC,10I10)                                        OPF07480
 0110 FORMAT(1H0,20X,9H       SNK,8I10)                                 OPF07490
 0115 FORMAT(1H ,20X,9H       SNK,8I10)                                 OPF07495
 0120 FORMAT(1H ,20X,9H       NOD,8I10)                                 OPF07500
 0130 FORMAT(1H ,20X,9H       ARC,8I10)                                 OPF07510
 0140 FORMAT(1H ,20X,9H    C(ARC),8(1PE10.2))                           OPF07520
 0150 FORMAT(1H ,20X,9H   CP(ARC),8I10)                                 OPF07530
 0160 FORMAT(1H ,20X,9H CP(RARC),8I10)                                  OPF07540
 0170 FORMAT(1H ,20X,9H  C(RARC),8(1PE10.2))                            OPF07570
 0180 FORMAT(1H ,20X,9H      RARC,8I10)                                 OPF07880
 0200 FORMAT(1H0/19H0TOTAL NETFLOW COST,1PE15.7)                        OPF07890
 0201 FORMAT(19H    PLUS FIXED COST=,1PE15.7)                           OPF07895
      RETURN                                                            OPF07900
      END                                                               OPF07910
      SUBROUTINE DEPCAP                                                 OPF07920
C GENERATES ALL POSSIBLE COMBINATIONS OF DEPOT CAPABILITIES             OPF07930
COMMENT DN=NUMBER OF DEPOTS                                             OPF07940
C         DA= DEPOT NYMBER                                              OPF07950
C         DL=SIZE LIMIT                                                 OPF07960
C         DC= SIZE                                                      OPF07970
C         N=TOTAL SIZE                                                  OPF07980
C         NMAX= MAX N                                                   OPF07990
      COMMON/DEPCOM/DL(05),DC(05),DN,NMAX,N,ALL,SUM(05),RL(05),DA       OPF08000
      INTEGER DN,DA,DC,DL,RL,SUM                                        OPF08010
      LOGICAL ALL                                                       OPF08020
      IF(DA.GT.0)GOTO1030                                               OPF08030
      IF(N.LT.NMAX)GOTO1020                                             OPF08040
      ALL=.TRUE.                                                        OPF08050
      RETURN                                                            OPF08060
 1020 N=N+1                                                             OPF08070
      MSIZ=N                                                            OPF08080
      DA=1                                                              OPF08090
      I=MIN0(DL(1),MSIZ)                                                OPF08100
      SUM(1)=I                                                          OPF08110
      GOTO1050                                                          OPF08120
 1030 DC(DA)=DC(DA)-1                                                   OPF08130
      SUM(DA)=SUM(DA)-1                                                 OPF08140
      MSIZ=N-SUM(DA)                                                    OPF08150
 1040 DA=DA+1                                                           OPF08160
```

```
      I=MINO(DL(DA),MSIZ)                                               OPF08170
      SUM(DA)=SUM(DA-1)+I                                               OPF08180
 1050 DC(DA)=I                                                          OPF08190
      MSIZ=MSIZ-I                                                       OPF08200
      IF(DA.LT.DN)GOTO1040                                              OPF08210
      IF(DN.EQ.1)GOTO1080                                               OPF08220
      I=0                                                               OPF08230
 1070 I=I+DC(DA)                                                        OPF08240
      DA=DA-1                                                           OPF08250
      IF(DC(DA).GT.0.AND.I.LT.RL(DA))RETURN                             OPF08260
      IF(DA.GT.1)GOTO1070                                               OPF08270
 1080 DA=0                                                              OPF08280
      RETURN                                                            OPF08290
      END                                                               OPF08300
```

APPENDIX IX

COMMENT FROM THE REGIONAL MUNICIPALITY OF NIAGARA ON THE NIAGARA STUDY

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COMMENT FROM THE REGIONAL MUNICIPALITY OF NIAGARA ON THE NIAGARA STUDY

The following letter, written by Mr. E. R. Simonen, our major contact with the Regional Municipality of Niagara, expresses concern primarily over the format of the program input. The reader should be aware that the difficulties he describes occurred before this manual was written. Our awareness of them strongly influenced the design of this manual. If the engineer/planner studies this manual he should now have no such difficulties, as we shall explain.

Item number one in the letter discusses the difficulty that is unavoidable when trying to set up a model and the data when there is no manual such as this to guide you.

Item number two discusses the problem of dealing with uncertainty in the data. At the present time, the most effective way of dealing with this is to compare the different results obtained with different data modifications. Although there is no quantitative measure available at this point for the influence of the uncertainty of a given piece of data, practical conclusions can be drawn simply by selecting solutions that are relatively stable with respect to the data modifications. This approach is described in Section 2.6.2 of Chapter 7.

Item number three expresses the caution that must be borne in mind concerning the validity of the model and the formulation of cost functions. The computer program has been designed and developed so as to achieve the greatest validity that is possible or practical; but only time and use can prove whether the solutions it produces are advantageous over those attainable by conventional methods. All we can say now is that the solutions do appear to be extremely good.

Lastly, Mr. Simonen suggests some additional items that would be useful in the printout of the least-cost facility combinations. These unit costs, etc. are easily calculated and it would be little trouble to include them for convenience. Such modifications to the program may be done by the individual user or a consultant, using the flowchart for subroutine LAYOUT in Appendix V.

TELEPHONE 685-1571

THE REGIONAL MUNICIPALITY OF NIAGARA

PUBLIC WORKS DEPARTMENT
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March 26, 1975

Prof. P. L. Silveston,
B & P Silveston Engineering,
550 Glasgow,
Kitchener, Ontario.
N2M 2N6.

Dear Sir: Re: Development of a Computer-Aided Sludge Study
File D. 13. 00.933

The following is submitted as a criticism or evaluation of the ALL02 computer program. This evaluation is based on the writer's involvement in the supplying of data to test the program with an actual situation and the review of results, and so may be interpretted as criticism from a user's point of view. The following points are noted as being the major areas of concern:

1. The major area of difficulty appeared to arise from a lack of clear understanding on our part of what form our input was to take. Once this was resolved, the data was produced quite simply in a relatively short time, once basic cost guidelines were established. It should be noted that this work was done by untrained junior staff (1st year University of Waterloo engineering students). Difficulties in the format of the input were also encountered; a matrix presentation consolidated over 300 pages of data into an easily readable and more understandable format. It is expected however, that difficulties of this nature are to be considered normal in the development of such a system, and will be resolved by the user's manual, and interpretation and costing advice provided by consulting engineers who will apparently be using this program.

2. There should be established in the program as an output, some form of sensitivity index to the variables in the input. Two examples are given which illustrate the need for such considerations:

. . . 2

i) sludge volumes from individual plants are difficult to predict when significant changes in process occur. The almost simultaneous provision of secondary treatment and phosphorus removal at one of the larger plants in Niagara Region is to occur in 1976. Sludge production is at best an educated guess. If this were to occur in another region, at one major plant, where the only other facilities were smaller plants, the choice of disposal method could be seriously affected. It is therefore suggested that the limits of sludge production in which an answer is valid should be at least approximated.

ii) The transportation costs were based on estimated rates and assumed loading/unloading times. (These latter are better described as time required to connect or disconnect a tank trailer from a tractor.) These can be significantly affected by many factors outside the control of the ultimate user. Again, some estimate of the effect of changing costs, travel times, etc. should be noted in the output.

3. As the basis for selection of optimal solution is economics, it may be useful, if it has already not been done, to have the approach reviewed by specialists in this field. It may also be advisable to seek the advice of those involved in private industry in comparable shipping operations as to the nature of problems which have not been foreseen or other complications that could deter from the validity of the program.

4. In the summary of the data, for presentation purposes, it would be useful if unit costs were given. This should be in the form of a weighted average cost, and the cost for each facility. This would point out those plants where particular efforts should be made to concentrate sludge solids to reduce volumes.

The above are, I believe, relatively minor criticisms of the approach and without commenting on the computer techniques, it appears that this program and approach with some refinement and more understanding and contact between user and programmer will be a useful tool in providing economic solutions to the problem of disposing or re-using sewage sludges. It has also been pointed out that the program is not limited to sewage sludges, but could also be used for locating and costing solid waste disposal systems.

Yours very truly,

ERS/asb

E. R. Simonen, P. Eng.,
Pollution Control Division
Engineer.

APPENDIX X

GLOSSARY AND SYMBOLS

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GLOSSARY AND SYMBOLS

Algorithm - a procedure or formula, usually expressed in terms amenable to computer programming, which is distinguished by the fact that it shows how to obtain a solution by performing only a finite number of basic computation steps.

Constraint - a restriction, in the form of an equality or an inequality, on the extent to which variables may be varied in order to create alternative solutions.

Distribution - the flows on all the transport links in a material flow network; when associated with an optimal solution, it is optimal for the given combination of facilities.

Facility - a treatment component other than a source.

Feasible - adjective describing that which satisfies all constraints and demands.

Fixed-charge - the first coefficient in a fixed-charge linear function that expresses cost as a function of size or quantity. This is the point where the function appears to intercept the cost axis.

Fixed-charge linear - adjective describing a function $y = a + bx$ if $x \neq 0$, but $y = 0$ if $x = 0$.

Global cost minimum - the point at the bottom of a depression of a total cost function, distinguished by the fact that any variation within the constraints of those variables, which may be varied to create alternative solutions, from the global minimum will increase the total cost.

Local cost minimum	- the point at the bottom of a local depression of a total cost function, distinguished by the fact that any very small variation of those variables, which may be varied to create alternative solutions, from the local minimum will increase the total cost.
Material flow network	- an abstraction which models a system using two kinds of components: transport links and treatment components.
Objective function	- the total system, expressed as a function of the variables describing a solution; its value to be minimized by finding the appropriate value of the variables.
Optimal	- adjective describing that which is best according to some criterion, eg., that which incurs the minimal cost or is most desirable while conforming to all given restrictions.
Potential facility	- a facility included in a model so that it may be used in the solutions; if a solution allocates any flow to a facility, then it is considered used in that solution.
Primal (dual)	- in reference to linear programming, the primal problem is the problem at hand, identified by the problem variables, the coefficients in the total system cost formula, the coefficients modifying the variables in the constraints, and the numbers representing the actual limits in the constraints. Every such primal problem can be changed into a dual problem, whose solution is easily related to that of the primal, by the following transformations: problem variables - coefficients in constraints coefficients in constraints - problem variables coefficients in total cost formula - limits in constraints limits in constraints - coefficients in total cost formula.

Primal-dual algorithm	- in reference to linear programming, an algorithm for obtaining a solution by repeatedly alternating between the primal and the dual problem; in special types of problems the solution is obtained most quickly by this method.
Programming (computer)	- the creation of a set of instructions for input to a computer in order to make it perform a desired schedule of operations.
Programming (linear)	- a type of mathematical programming which is applicable when the cost of a solution is linearly related to the variables which are varied to change the solution.
Programming (mathematical)	- the use of mathematical techniques to create an optimal design, schedule, or program, by systematically exploring the relationship between alternative solutions and their cost.
Solution	- a facility combination, perhaps including a possible sludge flow pattern from the sources through the facilities.
Transport Link	- the abstraction of the transporting of material from one point to another, or possibly just a representation of the possibility of transporting. The amount of material transported on a link, which may be zero, is called the flow on the link. A transport link is considered a component in a material flow network.
Transportation Problem	- a problem which can be modelled as a set of demand points and a set of supply (or servicing) points, with given quantities of demand and upper limits on the quantities of supply, the question being to find the material (or service) distribution pattern between the two sets of points such that the total cost of distribution is minimized, as determined by a total cost formula that

involves the quantity delivered between each pair of points. When the total cost function is linear, the problem can be solved quite efficiently by a special type of linear programming, and especially efficiently by a special type of primal-dual algorithm.

Treatment component - the point in a material flow network where transport links are in contact. Material flowing on incoming links may be treated, processed or just stored before it is distributed among the outgoing links. If there are only incoming or only outgoing links, the component is called a sink or source, respectively.

Unit cost - cost per unit quantity.

Variable cost - that portion of a fixed-charge cost function which changes with quantity.

"Winter" "Summer" "All-year" - in the context of the ALLO2 model, summer facilities are those that cannot be used during a part of the year called winter; winter facilities are those that store sludge in the winter destined to go to the summer facilities in summer, and themselves have no input in the summer; all-year facilities have no seasonal restrictions.

X_{im} - the flow on a transport link from point i to point m in winter

Z_{im} - the flow on a transport link from point i to point m in summer

A_m - the fixed charge for the facility m

B_m - the slope of the cost function of the facility m

V_m - the ratio "total flow out/total flow in" for facility m

L_m - the limit on total flow in for facility m

$H\ x$ - a function which takes the value 1 if x is greater than 0, and zero otherwise

C* - the minimal total system cost among the solutions stored

H* - the maximal total system cost among the solutions stored

ACKNOWLEDGEMENTS

We wish to thank the following people, who are not mentioned elsewhere in this manual, for their invaluable contributions that made it possible.

In the inital stages of research and formulation of the model:

G. M. Wood, G. H. Mills and K. Sakamoto, of the Ontario Ministry of the Environment

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Computer-aided planning of
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